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ABSTRACT

This manual was prepared for use by Peace Corps trainees and volunteers as a resource in gaining understanding and knowledge of basic irrigation principles and practices. It is intended as a practical handbook that can be understood by a generalist, with subject areas limited to those observed as being of most frequent concern to volunteers in their project activities in irrigation in agricultural programs abroad. Many of the irrigation problems, exercises, and equipment descriptions have been developed from on-the-job experiences of volunteers. The manual is organized into five units that cover the following topics: irrigation principles, water measurement, irrigation water control, draining, and irrigation planning and special information related to irrigated crop production and relevant problems. Units consist of information in a step-by-step format, illustrated by line drawings. Appendixes to the manual contain an explanation for irrigation implements and plans for animal-drawn implements useful in field preparation for irrigation. A reading list completes the document. (KC)

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Peace Corps

IRRIGATION PRINCIPLES AND PRACTICES

Prepared for the United States Peace Corps

by

Development and Resources Corporation

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INTRODUCTION

This manual has been prepared for use by Peace Corps Trainees and Peace Corps Volunteers as a resource in gaining understanding and knowledge of basic irrigation principles and practices. It is intended as a practical handbook which can be understood by the generalist. Subject areas have been limited to those observed as being of most frequent concern to Volunteers in their project activities in irrigation in agricultural programs abroad.

Many of the irrigation problems, exercises, and equipment descriptions have been developed from on-the-job experiences of Volunteers. Others have been included as a result of field observations made by Development and Resources Corporation's staff.

This manual is designed to convey insights into basic irrigation practices and techniques. Primary emphasis is given to providing explanation and illustration of irrigation practices as they are affected by soil-plant-water relationships. Care has been taken to make the content realistic and meaningful and presented with as non-technical a vocabulary as is possible.

The manual, to be most useful, should be used during training as a teaching guide and instructional tool. While the manual provides useful charts, drawings, structural diagrams and other meaningful information, it is recognized that some of the material presented would be meaningless, or at least inadequately understood, by the average generalist or by the individual with no previous irrigation experience. When the manual is utilized as an integral part of a training program in which trainees are being prepared for work in irrigated agriculture, and the material contained herein is presented and explained to trainees by qualified irrigation specialists, the manual can and will continue to be a valuable reference source for the Volunteer in the field.

Each of the principle units of the manual is complete and substantially self-contained. Topic coverage is sequential but does not preclude each unit being used as a review or as new material. With the aid of this manual, during and after training, a Peace Corps Volunteer should be able to apply the principles and procedures of acceptable irrigation practices on the farm for increased crop production to almost any irrigation problem he might encounter during his service abroad.

This manual has been prepared and is designed to provide close correlation between theoretical presentation of irrigation principles and the practical application of such principles. Trainers using this manual must necessarily keep in mind that practical application by the trainee of the principles presented is a prerequisite to Peace Corps trainee understanding of irrigated agriculture. To accomplish this task in a training program, the training site will need to provide adequate land (at least five acres for a program having 40 trainees), sufficient water to provide appropriate amounts for the crops grown, and sufficient and appropriate tools to accomplish the degree of sophistication required in a particular program. As is illustrated in the manual, however, it is extremely important in the instruction of irrigation principles and practices to Peace Corps trainees to continually emphasize that in the developing countries--indeed, even in the United States--large amounts of expensive irrigation equipment are not the only answer to doing a better job in increasing agricultural production. Good water control and management most often are of far more benefit.

Control devices, irrigation equipment of various kinds, etc., are only the tools of water management. What each Peace Corps trainee, who is to be involved in irrigated agriculture, must come to realize is that the right amount of water applied at the right time will produce the best results. This manual has been designed to help him gain that understanding.

Development and Resources Corporation sincerely hopes that Peace Corps Volunteers will find this manual a useful working tool and helpful in their project activities.

UNIT A - IRRIGATION PRINCIPLES

1. IRRIGATION - A DEFINITION

The production of crops, among other things, is dependent upon such climatic factors as temperature range, length of the growing season and the amount, frequency and distribution of rainfall. Man in his endeavor to control the variable aspect of these factors discovered that the moisture needs of growing plants could be supplied by the application of water. This knowledge enabled man to become independent of the vagaries of natural rainfall frequency and enabled him to grow crops in arid and semi-arid regions where soil conditions and other climatic factors are favorable to the growth of a particular type of crop. The application of water to soil for the growth of plants is known as irrigation.

Irrigation has been practiced by man since early recorded history. Egypt claims to have the oldest dam, a structure 40 feet high and 355 feet long erected over 5,000 years ago. An Assyrian Queen, before 2000 B.C., directed her government to remove water from the Nile River for the growth of crops. This canal is still in use today.

There are records of irrigation having been practiced in China over 4,000 years ago. King Yu of the Hsia Dynasty was elected king because of his outstanding work in water control. The Tu-Kiang Dam was built by Mr. Li during the Chin Dynasty in 200 B.C. and continues to irrigate 500,000 acres of rice. The Grand Canal used for navigation and irrigation is some 700 miles long and was built between 589 and 618 A.D.

In Asia Minor, a great civilization existed in the valleys of the Euphrates and Tigris Rivers. The remains of a large canal 400 feet wide, 30-50 feet deep and 250 miles long still exists. This canal is believed to have carried ten times the volume of water of the River Thames. Many theories have been advanced to explain the decline of this civilization. Among the suggested possibilities are the lack of sufficient water, poor soil management methods, invasions, and the use of slave labor to run the farms.

There is also a record of irrigation at an early date in Ceylon and India.

The Spaniards reported the presence of water storage and conveyance structures in Mexico and Peru. Cortez reported irrigated areas

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in Mexico. The early missionaries brought their knowledge of irrigation from the Mediterranean countries to Mexico and the Southwestern United States.

The first recorded large scale irrigation system in the United States was established by the Mormons as a cooperative project in the Salt Lake Valley in 1847.

2. IRRIGATION METHODS

Water is applied to soil in a variety of irrigation methods each of which has some advantages and disadvantages.

Flooding

Field flooding or wild flooding is the simplest method. It involves merely releasing water from head ditches. This method is generally employed when the field is quite irregular and a large stream of water is available. It is best suited to the production of forages and small grains. Best results are obtained if some land leveling is performed before the initial irrigation.

Border Method

The border strip method is a modified field flooding system in which small levees or dikes, called borders, run down the slope of the field in the direction of water movement. This partitions or divides the field at right angles to the flow of water. Generally, a cross slope of 0.2 foot per 100 feet is disregarded. At this point it might be well to define an irrigation slope. This is usually understood to be the amount of fall per unit length of strip. Thus, a strip that has a drop or difference in elevation of 1 foot per 100 feet of strip is said to have a one percent slope.

In designing a border strip system a number of factors must be considered such as the crop to be grown, the type of soil, and the slope of the land. A narrow strip width will cut down erosion as less water will need to be released and there is less tendency for the water to channelize. The length of the strip is determined by the type of soil, the percentage of slope, and the amount of water available in the head ditch. Ordinarily, the length of a strip on a medium textured soil is about 1,000 feet. Sandy soils should be irrigated in strips 200 to 300 feet long. Clay soils with a low intake rate should be irrigated very slowly in strips of 2,000 feet and more. The entire length of the strip under the same soil conditions should carry approximately the same percentage slope.

The width of the strip depends upon the steepness of the irrigation slope, the amount of cross slope, and the size of the irrigation stream. Because large streams of water tend to channelize more rapidly on steep slopes and thus accelerate erosion, it is advisable to keep the strip width narrow. For slopes ranging from 0.4 to 0.5 percent, strip widths from 20 to 30 feet are recommended. For greater slopes, a maximum width of 15 to 20 feet is best. On slopes of 0.15 to 0.3 percent, widths up to

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100 feet or more can be used. The cross slope should not be greater than 0.2 to 0.3 foot since strip widths will be determined by this factor. For example, a cross slope of 0.3 would determine the strip width of a field with a one percent cross slope to be 30 feet. The amount of water available for irrigation may also determine the width of the strip to be irrigated. For example, if 250 gallons of water per minute are available to a strip that requires 10 gallons per minute per foot of width, the width of the strip to be irrigated will be 25 feet.

The border strip method is most often used in the production of forages and small grains.

Furrow Irrigation

The furrow system differs from the flood and border strip methods in that water does not flow over all of the surface soil. When furrows are used, only one-fifth to one-half of the surface is wet. The furrow method can be used on slopes too steep for the flood or border strip methods. This method is used for the production of row crops such as sugar beets and corn. A variation of the furrow method is the shallow furrow or corrugation method. Corrugations are employed in the production of grain and forage crops. Corrugations demand a fairly level cross slope.

Furrow lengths vary from 100 to 1,500 feet. Slopes of 5 to 10 feet per 1,000 feet of furrows are advisable. Excessively steep furrows result in soil erosion and excessively deep percolation at the upper end of very long furrows. The distance between furrows is regulated by the type of crop grown and the lateral movement of water between furrows. The depth of the furrow also depends upon the root zone of the crop. For example, furrows 8 to 12 inches deep can be employed in orchards while a depth of 3 to 5 inches is sufficient for sugar beets and similar crops.

Basin Irrigation

Basin irrigation is the traditional method used in many underdeveloped regions of Asia and the Far East. This method has led to many serious problems. It consists of running a relatively large quantity of water into an almost level area surrounded by levees and allowed to penetrate into the soil. Land suited to this type of irrigation is rather level and has a definite drainage pattern. It is useful when soils such as clay with a low intake rate cannot take in sufficient water during the time a flow runs over it. In some regions where stream flows are erratic and large amounts of water need to be utilized in a short period of time, the basin system is ideal.

In the Far East, entire mountainsides are occasionally terraced and converted into rice paddies. Spillways permit the water to flow from one terrace down to another.

This method of irrigation has led to many serious problems. There is a tendency to over irrigate, land is eroded quite seriously, and salinity often times becomes a problem. Where double cropping is practiced, the second crop is often irrigated in the same manner as a rice paddy with a resulting decrease in yield because of too much water. Water may be in short supply during the second or short growing season. Careless irrigation practices may bring about a shortage of water towards the end of the growing season, resulting in smaller yields, than if more efficient methods, such as furrow irrigation, had been used.

Soil salinity often becomes apparent after several years of basin irrigation when drainage facilities are not adequate and the water table has risen. A change in traditional irrigation practices may help to alleviate these problems.

Sprinkler Irrigation

The application of water to the soil in the form of spray, somewhat similar to rain, is known as sprinkler irrigation or sprinkling. This method of water application was first used about 1900 in humid regions as a supplement to rainfall. With the advent of lightweight aluminum pipe, widespread availability of cheap fuels and electricity, and more efficient pumps, the number of sprinkler irrigation systems has greatly increased. There are a number of advantages and disadvantages of sprinkler irrigation that should be considered. The conditions that favor sprinkler irrigation are:

1. Less total water is required than with other methods due to higher irrigation efficiency.

2. Can be installed on undulating land that is too costly to level.

3. An even distribution of water is obtained.

4. Can irrigate soils too porous for good distribution by surface methods.

5. Effective on shallow soils with a topography which prevents proper leveling for surface irrigation.

6. Labor costs are generally lower.

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7. Can irrigate steeper soils with less erosion hazard.

8. Water measurement is easier with sprinklers than with surface methods.

9. Small quantities of water can be applied frequently with greater ease than other methods.

There are also a number of disadvantages that should be considered. They are:

1. A rather high cost of initial installation.

2. Some water is lost due to evaporation and wind.

3. The removal of spray materials from foliage.

4. The cost of power to provide pressure must be added to the irrigation cost.

5. Water falling on the soil surface may cause crusting, thus, decreasing infiltration rates.

6. Moistening the foliage may increase the incidence of disease.

Sprinkler systems are also utilized for frost protection and fertilizer application. Sprinkler systems have been used for many years to protect berries, vegetables, citrus, and almonds from frost damage. In the case of trees in cold climates, care should be exercised so as not to break limbs with ice accumulations. Soluble types of fertilizers can be injected into the system and be applied quite uniformly over the land surface.

Three general types of sprinklers are used, namely fixed nozzles, perforated pipe, and rotating sprinklers. The fixed nozzle is attached rigidly to the pipe and parallel pipes are installed about 50 feet apart on posts. Perforated sprinkler systems are generally used in orchards or nurseries. They do not cover a very wide strip. The rotating sprinklers are the most popular because they supply water at a slower rate using a relatively large nozzle opening. The large opening is an advantage where waters containing silt and debris are utilized because less stoppage of sprinklers occurs. For rotating sprinklers, pressures normally range from 30 psi (pounds per square inch) for the smaller sprinklers to over 100 psi for larger units.

A sprinkler system consists of the sprinkler, riser pipe, lateral distribution pipe, and main line pipe in addition to the pumping plant. The sprinkler systems are generally classified as portable or semi-permanent. The semi-permanent system has the main line buried and the laterals and sprinklers remain fixed during the irrigation season. With the portable system, the laterals and sprinklers are moved after each individual irrigation.

The success of a sprinkler irrigation system depends on the correct design and efficient operation. The basic information used in designing a system comes from the soil characteristics, water supply, climate, and the crop to be irrigated. Soil characteristics include soil texture, depth, permeability, and available water holding capacity. Water information includes the location of the water delivery point in relation to the field to be irrigated, the delivery schedule of the water, and the quantity of water available. Crop information includes the root zone depth, maximum water use per day, and a knowledge of the growth stages of the crop. Climatic data includes natural precipitation, wind velocities and directions, temperature, and humidity.

Water should be applied at a rate where high efficiency in regard to intake and distribution is obtained and no runoff occurs. The design should allow for the peak water use demands of the crop during its growing season, and for unavoidable losses such as deep percolation, evaporation, and interception by the above ground parts of the plant.

Subsurface Irrigation

Subsurface irrigation involves the application of water directly under the soil surface. Conditions that favor subsurface irrigation are a highly permeable sandy loam or loam surface soil, an impervious subsoil at a depth of six feet or more, and uniform topographic conditions with moderate slopes. In the San Joaquin-Sacramento Delta country of California large tracts of land are 2 to 10 feet below river surface which is controlled by levees. Irrigation water is siphoned over the levees and distributed in channels to ditches which are 2 to 3 feet deep and about 150 to 300 feet apart. This arrangement provides adequate water to irrigate small grains and root crops.

A major hazard involved in subsurface irrigation systems in hot climates is the alkali condition that develops from the upward capillary water flow from a shallow water table.

Subsurface irrigation is generally restricted to areas having a particular combination of factors.

TABLE 1

COMMON IRRIGATION METHODS AND THEIR APPLICATION

Method	Adapted to ----	Conservation Features	Problems and Limitations
Basins	Close growing crops and rice on flat land with sandy soil.	Provides good control of water applied. Good for alkali control.	Accurate land leveling is generally required. Border ridges may interfere with movement of farm machinery. Special provisions must be made for drainage.
Borders	Forage crops or grain on uniform slopes up to 3%; established pasture on uniform slope up to 6%. Best adapted to light soils.	Provides uniform wetting and efficient water use. Utilizes large water streams safely and thus less time is required to cover area.	Topography must be fairly level or soils deep enough for adequate leveling. The available stream must be large enough to irrigate a border strip of practical size. A light irrigation may be difficult to apply efficiently.
Corrugations	Close growing crops on sloping land with soil to take water. Extreme care is needed in applying water to slopes of more than 2%.	Provides uniform wetting and prevents erosive water accumulation on land too rolling or steep for borders or basins. Makes use of small streams.	Labor requirements are high. Irrigation streams must be carefully regulated. It is not well suited to gentle slopes. Rough field surface makes machine operation difficult.

TABLE 1 (continued)

Method	Adapted to ----	Conservation Features	Problems and Limitations
Furrows	Row crops, truck crops, orchards, vineyards, and berries on gentle slopes with all but coarse textured soils.	Provides no conservation features unless furrows laid on nearly level land on the contour and water applied with extreme care.	Construction and maintenance of the furrows is expensive. Larger streams than necessary must be applied to get water to advance rapidly.
Sprinklers	Nearly all crops on any irrigable soil except in very windy hot climates.	Provides uniform wetting, eliminates erosion, and gives high water use in most places.	Wind distorts sprinkler patterns and causes uneven water distribution. A stable water supply is needed for economical use of equipment. Water must be clean and free of debris. Requires highest initial investment.
Controlled flooding	Close growing crops on rolling land; pasture sod established by corrugations or sprinklers.	Provides water control and fairly uniform wetting where land cannot be used for other methods.	Irrigation efficiency is generally low. Small streams are not easily used.

(S.C.S. Inf. Bul. No. 8)

3. THE SOIL AS A RESERVOIR FOR WATER NEEDED BY PLANTS

The soil acts as a reservoir for water needed by plants. About one-half of the water that is in the soil when it is saturated moves down through the large pores through the root zone and is lost insofar as plant use is concerned. This water is known as gravitational water.

Approximately one-half of the water that remains in the soil (one-fourth of the total water) is available to plant roots and is known as capillary water. This water is free to enter plants and be utilized for growth processes and transpiration.

The remaining one-half of the water that remains in the soil is held so tightly to the soil particle, that it is unavailable to plant roots. This water is held with a force greater than 15 atmospheres of pressure. That portion of the unavailable water held by forces of 15-31 atmospheres of pressure is known as hygroscopic water.

When all of the pore space of a soil is filled with water, it is said to be saturated. The point where drainage ceases and the maximum amount of water is retained in the soil is known as the "field capacity". Field capacity exists under approximately one-third of an atmosphere of pressure.

Since the function of irrigation is to provide water to the soil for the use of plants it is well to examine the soil. A typical soil can be looked upon as a three phase system consisting of approximately one-half solid material, one-fourth gas and one-fourth liquid. The solid phase consists largely of inorganic materials known as sand, silt, and clay ranging in size from 2 mm. to less than 0.002 mm. Sand particles are the largest (2.00 mm. - 0.05 mm.) in size and consist mainly of quartz. Sand has a gritty feeling when rubbed in the hand. Silt particles (0.05 mm. to 0.002 mm.) have a velvet-like feeling to the hand while clay (less than 0.002 mm.), is the smallest size fraction and has a sticky feeling when moistened in the hand. In most soils there is also a small portion of organic material.

The various size fractions of the soil are mixed into different combinations called soil textures. For example, a soil texture such as loam consists of 28-50 percent silt, 25-52 percent sand, and 7.5 to 27.5 percent clay. A soil containing equal amounts of the three separates is a clay loam.

The various textures as indicated on the textural triangle (Figure 1) are generally grouped into three categories. Sands, loamy

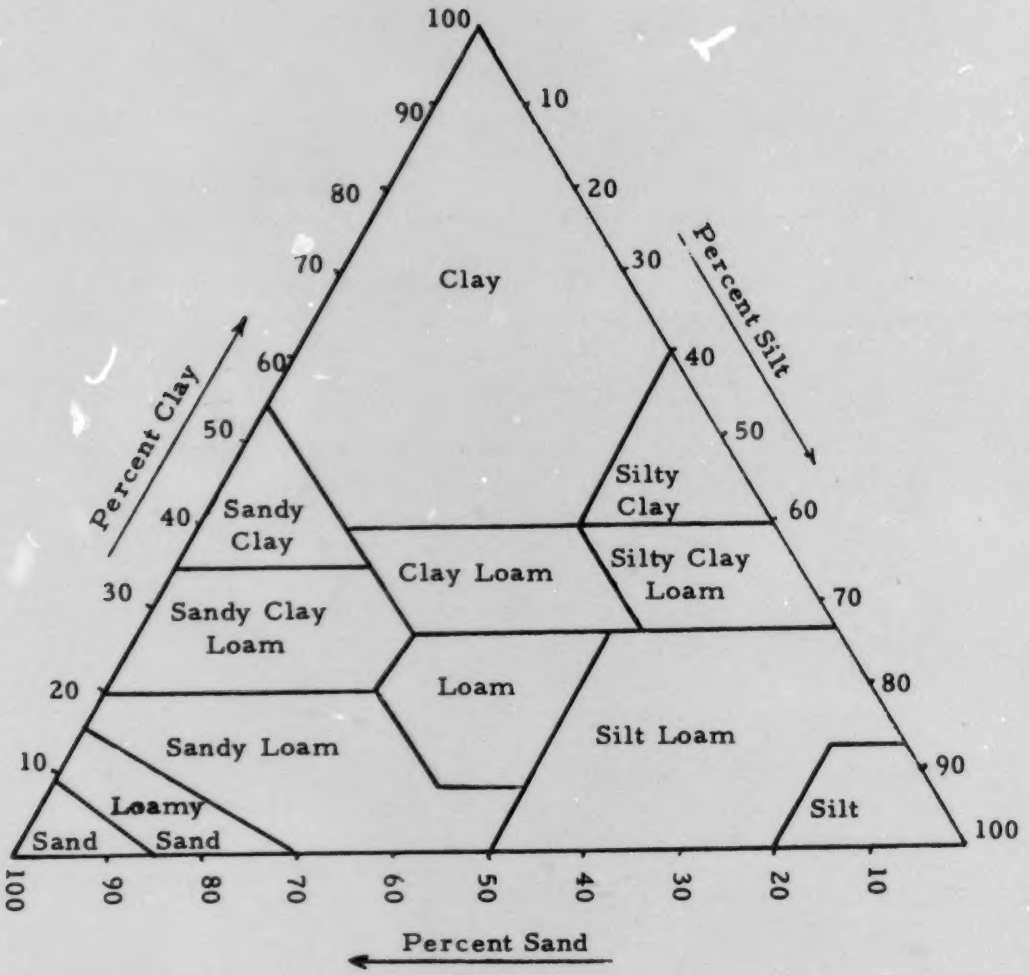

FIGURE 1

SOIL TEXTURAL TRIANGLE showing the percentages of clay, silt, and sand in the basic soil textural classes.

(U. of Calif. Agri. Ext. Ser.)

sands, and sandy loams are usually referred to as coarse textured soils; loams and silt loams are medium textured soils; while clay loams, silty clay loams, and clays are known as fine textured soils. The fine textured or clay soils are known as heavy soils and the coarse textured soils as light soils.

It is interesting to note that the terms heavy and light soils originated from the ease with which tillage implements are drawn through the soil. Thus, clays are difficult soils to draw implements through in contrast to sands in which tillage requires less power.

Soil texture has a large influence on the amount of water that can be stored in soils for plant use and the rate at which water moves through the soil. The coarse textured soil will be able to hold for plant use only 1/2 to 1-1/2 inches of water per foot of soil. At the other extreme, the fine textured soil will hold from 1-3/4 to 2-1/4 inches per foot of soil. Familiarity with soil textures will assist in making the irrigation job easier and more efficient.

Generally, clay will hold about three inches of water per foot, or twelve inches in a four foot root zone. When six inches of this water has been utilized, the plant is in danger of permanent wilt. For that reason, it is generally agreed by most irrigators that water application is needed immediately when soil moisture falls between 50 and 60 percent of field capacity.

Since the greater part of the roots (60-75 percent) are in the top two feet of the root zone, irrigation must be applied when this portion of the soil profile approaches 50 percent depletion, even though the lower two feet still may have enough water to give a cumulative total of more than 50 percent of field capacity.

Most crops in deep, uniform soils use moisture more slowly from the lower root zone than from the upper soil. The top quarter is the first to be exhausted of available moisture. The plant then has to draw its moisture from the lower three-quarters of root depth. This places a stress on the plant, and adequate moisture to sustain rapid growth cannot be extracted by the roots.

Soil structure is a term used to describe the arrangement of the soil particles. Structure refers to a compounding or aggregation of soil particles into various forms such as platy, blocky, prismatic, etc. The moisture and air relationships of a soil are influenced by structure. An

example of this is when soils containing some clay are trampled by animals while it is wet and the clay fills the pore space, thus creating a soil that is more dense. Upon drying, this soil forms a massive structure and is said to be puddled.

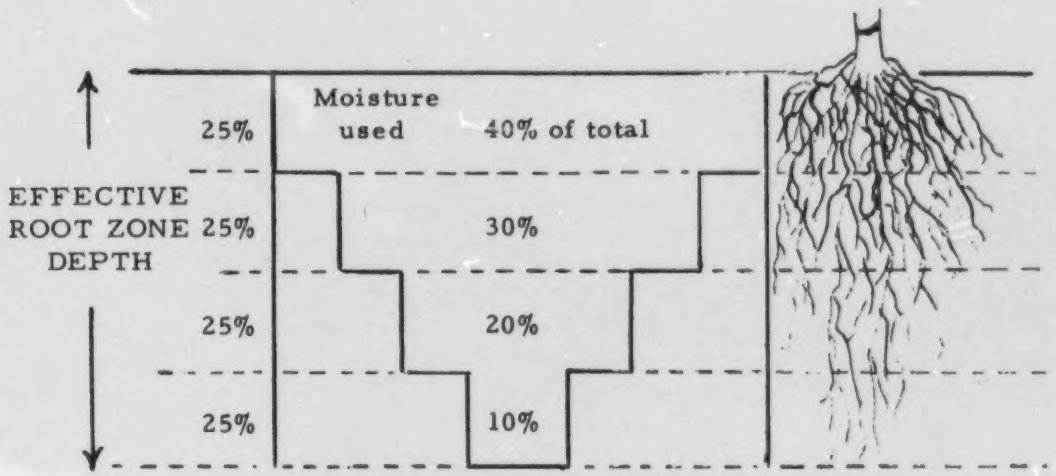

FIGURE 2

Moisture use in relation to root zone and available moisture.

(S.C.S. Inf. Bul. No. 199)

Soil Density and Pore Space

The density of soils is generally measured by two methods known as "bulk density" and "particle density". Bulk density refers to the specific gravity of a volume of soil including its pore space. Thus, a cubic foot of soil including its pore space weighing 72.0 pounds, when divided by the weight of a cubic foot of water, (62.4 pounds), would have a bulk density of 1.15.

Particle density is a term used to measure the specific gravity of a soil excluding pore space. In other words, we are concerned with

measuring the *density of the soil particles* without considering the air space between particles. Thus, if we assume that the soil mentioned in the preceding paragraph has a pore space of 48 percent, we can determine the particle density by dividing the weight of the soil particles (72 pounds) by the weight of an equal volume of water (52 percent of 62.4 pounds), 32.4 pounds. The particle density will be 2.22 in this example. For a given soil, the particle density will always be greater than the bulk density. For most mineral soils, the particle density will average about 2.65. Large portions of organic matter will tend to lower this figure. Bulk densities of soils will vary according to the texture and pore space of a given soil. Bulk densities of coarse textured soils are usually in the range 1.3 to 1.8 while fine textured soils are usually in the range 1.0 to 1.3. Organic soils, depending upon the content of organic matter, usually have a range 0.2 to 0.6.

All of the calculations involved in determining the particle density and bulk density are based on the oven dry weights of soil. Thus, the variable of moisture content is eliminated. The bulk density and particle density of a soil, if known, can be used to determine the "pore space" of a soil according to the formula:

$$PS = 100 - \left(\frac{B.D.}{P.D.} \times 100 \right)$$

PS = pore space in percent

BD = bulk density

PD = particle density

If we substitute the previously determined figures for bulk density and particle density, we obtain a pore space of:

$$PS = 100 - \left(\frac{1.15}{2.22} \times 100 \right)$$

$$PS = 100 - 51.8$$

$$PS = 48.2\%$$

The percentage of pore space in a soil is important because it will determine the amount of water that a given soil can hold.

The movement of water into the soil is known as infiltration, while water movement within the soil is known as percolation. Fine

textured soils generally have a lower infiltration rate measured in inches per hour than coarse textured soils. The long term infiltration rate refers to the number of inches of water that enters the soil per hour after a constant infiltration rate has been established. Some values are shown in Table 2.

TABLE 2

LONG TERM INFILTRATION RATES FOR DIFFERENT SOILS

Soil Type	Infiltration Rate in Inches Per Hour
Clay	Less than 0.1
Clay Loam	0.1 - 0.2
Silt Loam	0.3 - 0.7
Loam (silt)	0.8 - 1.2
Sandy Loam	1.3 - 2.4
Sand	Over 2.5

Water Retention in Soils

Water is generally considered to be the universal solvent. The water molecule is dipolar in nature which means that one end of the molecule is negative in charge while the other is positive. Since opposite charges attract each other, this property permits the molecule to adjust to most materials.

Another property of water is its relatively high surface tension. Surface tension is a measure of the cohesion or attraction of water molecules to other water molecules. In contrast to the cohesive forces, there are the adhesive forces. Adhesion is the attraction of water molecules to other molecules such as glass or soil.

These properties of water when combined with the various soil particle sizes have a profound influence upon the movement, storage capacity, and retention of water in the soil. Coarse textured soils consisting of large sized particles tend to have fewer, but individually larger, diameter pores than fine textured soils with small sized particles such as clay. Thus, a clay soil will have greater total pore space, a lower bulk density, and smaller diameter individual pores than a coarse textured soil such as loamy sand.

Since water has a high adhesive force, it is understandable that water is retained to a greater extent in the fine textured soils than in the coarser textured soils. This can be visualized by comparing the ease with which water can be poured through a two inch diameter pipe to the difficulty of moving water through a capillary tube.

The relationship of adhesion of water to soil particles can also be considered from the viewpoint of specific surface. Specific surface refers to the amount of surface area exposed to air or water. For example, a solid one inch cube has a specific surface of six square inches. If the same cube is sliced in three places giving eight one-half inch cubes, the total surface will be twelve square inches. Therefore, a soil such as clay will have a high specific surface and, consequently, will have a large percentage of the water adhering to the particles.

Water Uptake by Plants

Water not only aids in the absorption of mineral nutrients by plants but is itself necessary for plant growth. Growing plants contain more water than any other compound.

Water enters the plant through the root system by the process of absorption and is lost chiefly by the process of transpiration from leaves.

Transpiration

A large supply of water is necessary for all the activities of plants such as photosynthesis and growth. A young leaf often contains up to 90 percent water. The water content of a leaf at any specific time represents only a fraction of the water reaching the leaf during the growing season. This large water requirement is necessary because water is constantly being lost by evaporation from the cells of all aerial parts, especially the leaves. The evaporation of water from the exposed surface of a plant is called transpiration. The bulk of the transpiration water loss is through the leaves.

The leaf has a remarkable structure for capturing carbon dioxide from the air. On the underside of most leaves, a profusion of small openings called stomates are found. The opening and closing of the stomates is controlled by adjacent guard cells which are activated by light. Immediately inside the epidermal cells, the stomatal passage leads to the sub-stomatal air chambers. The soft spongy tissue surrounding the air chambers is bathed in water which absorbs the carbon dioxide from the air trapped in the air chambers. Since the soft spongy tissue is constantly evaporating water into the intercellular air chambers, there is a movement of water vapor into the outer atmosphere by diffusion through the stomata. The epidermal cells of a leaf account for some water loss but this is a relatively small amount in land plants because of the presence of an almost impervious material known as cutin. Cuticular transpiration is believed to account for from 3 to 15 percent of the water lost by transpiration with the remainder being lost through the stomata.

The greater part of the water absorbed by plants is lost by transpiration. The quantity of water lost is surprisingly large. A vigorous sunflower plant has been estimated to transpire approximately 400 pounds of water in a 100 day growing season. An individual corn plant has been calculated to remove 54 gallons of water from the soil in a season. This is 90 times the amount of water needed by the plant for all purposes other than that lost by transpiration. A mature apple tree may lose 95 gallons of water per day. For one acre containing 40 trees, this would amount to a transpiration rate of 480 tons of water in a midsummer month.

The mechanics of stomatal transpiration consist, first of the evaporation of water from the saturated spongy cells surrounding the sub-stomatal air chambers and, second, the diffusion of the water vapor through the stomata. The evaporation of water from the walls of the cells adjoining the air chambers creates a water deficit in the walls. As a result of this deficit, the walls of the cell imbibe more water from the protoplast. Withdrawal of water increases the concentration of dissolved substances and tends to draw water by a process known as osmosis from neighboring cells that contain more water. This process repeats from cell to cell until eventually water is withdrawn from the water conducting tissues known as tracheids and vessels of the veins which are in turn connected to the main conducting tissue of the leaf, stem, and root known as the xylem. Thus, the moisture deficit is transmitted to the root system and a continuous stream of water results. This continuous stream compensates for the loss of water in the form of vapor from the stomata.

There are a number of external factors that greatly influence the rate of transpiration. These factors are radiant energy, air movement,

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humidity and temperature, and soil conditions. Radiant energy is a dominant factor since the stomata of most plants are open in light. An intensity curve shows a maximum rate of transpiration more or less corresponding with light intensity. Absorption of radiant energy is largely within the visible light spectrum although some of the longer wave lengths (infrared) are also absorbed. Radiant energy absorbed that is not used for photosynthesis is transformed into heat and becomes a factor in water vaporization.

Humidity conditions in the atmosphere are usually expressed as relative humidity. Relative humidity refers to the amount of moisture present in the atmosphere at a given temperature compared to the total amount of moisture the atmosphere is capable of holding at the stated temperature. The higher the temperature, the greater the amount of moisture the atmosphere can hold. Thus, if there is a higher relative humidity within the sub-stomatal air chamber than in the outer atmosphere, there will be a diffusion gradient and a loss of water vapor to the outer atmosphere. A rise in temperature, moderate air currents, and leaf movement also increase the rate of transpiration.

The size and shape of the leaf affect the amount of water transpired. In general, the modified leaves of desert plants such as the cactus lose less water than the leaves of a temperate region plant such as the sunflower. Water loss is also regulated by the stomata in that when they are completely closed, transpiration is stopped; however, a decrease in diameter of 50 to 75 percent apparently has only a slight effect on rate of transpiration.

It is apparent that the water movement in plants is affected by the water loss from transpiration and the amount of water absorbed from the soil. Some factors that affect the amount of water absorbed from the soil are the extent of the plant root system, the amount of water present in the soil and the concentration of solutes in the soil water.

Root Systems

The roots of plants are the organs which are in contact with the soil and the soil solution and, therefore, are able to absorb water and salts. The plant root system may be viewed as a large probing network that exploits the water and salt resources of the soil. In addition to functioning as an absorption unit, transport of water and salts and anchorage in the soil are also functions of the root system. There are structurally two main types of root systems; namely, the tap root and the fibrous root system. The tap root system consists of a primary or central root which grows more rapidly than any of the branch roots. The branch roots arise from the central root. In some plants such as the carrot, radish, and beet, the diameter of the tap root may exceed that of the stem.

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The fibrous root system has no central axis and most of the branches grow to approximately the same length and diameter. This type of root system may be constituted of relatively thin roots as in annual plants or some parts may grow to larger diameters as in most familiar trees.

Numerous studies of the distribution of root systems have shown that the extent and mass of root development is generally greater than previously supposed. Root growth habits vary with the species of plants and reflect the influence of soil and climatic factors. In arid regions, alfalfa roots of two month old plants have been recorded at a depth of five feet. In general, the more extensive the root system, the greater the absorption capacity.

Available Moisture for Plant Use

Water may be classified as unavailable, available, and gravitational or superfluous. If water is applied to a soil until all of the pore space is filled, the soil is said to be "saturated". About one-half of this moisture will be lost due to the pull of gravity. Usually this gravitational water has drained away within about 24 hours following application. Except for rather slight losses due to evaporation from the soil surface and continuing drainage due to gravity, the soil moisture remaining indicates the "field capacity" of that soil.

In practice, field capacity is usually determined two days after an irrigation. A soil will come to field capacity more quickly when an active crop is growing than when there are no roots removing water from the soil.

Field capacity can be measured by determining moisture content of soil after an irrigation sufficiently heavy enough to ensure thorough wetting of the soil. Observing the decrease in moisture by making moisture determinations at different times after irrigation is valuable in understanding and properly interpreting the field capacity characteristics of a soil.

If there are plants growing on the soil, the moisture level continues to drop until it reaches the "permanent wilting point" (p.w.p.). Soil moisture content near the wilting point is not readily available to the plant. Hence the term "readily available moisture" has been used to refer to that portion of the available moisture that is most easily extracted by the plants, approximately 75 percent of the available moisture. After this point, the plants are unable to absorb water from the soil quickly enough to replace water lost by transpiration.

Water is held in the soil at a certain tension force. Soil moisture tension is normally between 1/10 and 1/3 atmospheres (atm.). The tension at which permanent wilting occurs can vary from 7 to as high as 40 atm., depending upon consumptive use, crop, soil texture, etc. Formerly, it was often thought that plants thrive equally well regardless of the moisture level, as long as this level is between field capacity and permanent wilting. It is more logical, however, to assume that if water is so abundant as to be easily absorbed from the soil, the plants should thrive better. This is supported by research findings. Maximum yields are obtained when the moisture level during the critical growing season is maintained relatively high. On the other hand, if a crop is watered too frequently, even with light irrigations, part of the soil will be so constantly saturated that the crop will suffer from poor aeration.

The soil moisture content when plants permanently wilt is called the permanent wilting point or the wilting coefficient. The permanent wilting point is at the lower end of the available moisture range. A plant will wilt when it no longer is able to extract sufficient moisture from the soil to meet its needs. Wilting depends upon the rate of water used by the plant, the depth of the root zone, and the water holding capacity of the soil.

Among the root crops, sugar beets readily indicate need for water by temporary wilting, particularly during the warmest part of the day. Crop growth should not be retarded by lack of available soil moisture. The practice of withholding irrigation until the crop definitely shows a need for water is likely to retard growth. It is essential to maintain readily available water in the soil if crops are to make satisfactory growth.

4. METHODS OF MEASURING SOIL MOISTURE CONTENT

The measurement of the water storage capacity of soils and the amount of water in soils are of vital importance in determining the quantity of water to be applied in an irrigation. Field capacity has been previously defined as the maximum amount of water that a soil can hold against the force of gravity. Therefore, any amount of water applied to a soil beyond the field capacity will be lost to deep percolation. The determination of the amount of moisture that is available to plants in an unsaturated soil is an important consideration in calculating the water needed to bring the soil to field capacity. Soils vary in the amount of water they can hold at field capacity. Some of the factors that cause this variation are the depth and texture of the soil and the percentage of moisture in the soil at the permanent wilting point. Some of the methods employed in the determination of volumes of water available to crops are considered in the following sections.

Oven Dry Method

One of the most common methods of determining soil moisture content is the oven dry method. This method consists of taking a soil sample of approximately 200 grams, determining its exact weight, and drying the sample in an oven at a temperature of 105 to 110 degrees centigrade for 24 hours after which the sample is again weighed and the moisture loss determined by subtracting the oven dry weight from the moist weight. The moisture content is expressed as a percentage of the oven dry weight of the soil. For example, if a 212 gram moist soil sample weighs 197 grams after drying, the percentage of moisture is calculated by dividing 197 into 15 which results in an answer of 7.6 percent. A note of caution is to remember to subtract the weight of the container from both the moist and dry weight determination.

Tensiometer

The tensiometer is a device consisting of a porous clay cup filled with water and attached to a vacuum gauge or a mercury manometer. A hole is dug to the depth at which the measurement is desired and the cup and connecting tube filled with water and placed in the soil. The soil is firmly packed to insure good contact. A temporary connection is established between the water in the soil and the water in the cup. When water moves out of the cup, a suction or tension created in the cup is registered on the gauge. Variations in soil moisture are registered by the tensiometer as long as the tension does not exceed 0.8 atmospheres. At greater tensions,

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air enters the closed system through the pores of the cup and the device is no longer accurate. Since the bulk of the available water in sandy soils is represented by approximately 0.8 atmospheres of pressure, tensiometers are best suited to these areas. Some representative moisture tensions are: sand 5 atm., loam 19 atm., and clay 35 atm.

Gypsum Block Method

The electrical properties of conductance or resistance can be used to indicate the moisture content of soils. The electrical properties of soils change with a change in the moisture content. Porous blocks of gypsum containing electrical elements are placed in the soil and they change their moisture content as the soil moisture content changes. It has been determined that gypsum (plaster of paris) blocks tend to achieve a moisture equilibrium with that of the soil in that, as the moisture increases, the amount of gypsum in solution increases and the resistance between the wire embedded in the block decreases. Materials such as fiber glass and nylon have also been used for making blocks.

Gypsum blocks operate best at tensions between 1 and 15 atmospheres, while nylon blocks are more sensitive and function best at tensions less than two atmospheres. Because of their solubility, gypsum blocks deteriorate in one to three seasons. Gypsum blocks are less sensitive to soil salts than nylon and fiber glass blocks.

The procedure for using gypsum blocks consists of digging a hole to the lowest depth from which moisture data is desired. At each desired interval from the bottom upward, a gypsum block is buried and its leads are brought to the surface. Thus, a number of blocks at different depths are buried in one location. It is customary to use a color code for the leads if a series of readings are being recorded at each location. For example, the deep leads might carry a red marker, medium leads a white marker, and shallow leads a blue marker. Thus, if all red leads indicate the moisture content at a four foot depth, it greatly simplifies the task of the recorder. Small transistorized meters for reading electrical properties are available from commercial outlets. The gypsum blocks with electrodes and leads installed are also available from commercial sources. There is great variability between gypsum blocks, so they should be carefully calibrated before use.

Radio-isotope Methods

A method of measuring soil moisture is based upon the ability of water to slow the velocity of fast neutrons. This method consists of a

source emitting fast neutrons into the surrounding soil. The fast neutrons that are slowed down by the water are recorded when they reach the counting tube. The fast neutrons are not recorded by the counter. The greater the water content of the soil, the greater the number of slow neutrons reaching the counting tube. The hydrogen in the water is the principal element absorbing fast neutrons and, therefore, a good correlation between the amount of water in the soil and the number of slow neutrons is registered by the counter. Chlorine and boron also absorb fast neutrons; consequently, soils containing these elements will indicate moisture contents higher than the correct value.

To install the device, a hole is dug with an auger and a metal tube is driven into the hole after which the neutron source and counting unit are placed within the hole and lowered to the desired depth. The moisture content of the soil surrounding the source and counter is proportional to the reading on the counting unit. The reading on the counter will also be influenced by the location of the unit in that when the unit is near the surface, a different reading will be obtained for the same moisture content than when the unit is located well beneath the surface. Also, the zone of influence of the unit decreases as the moisture content increases.

The neutron method is presently employed almost exclusively at research stations. Efforts are being made to lessen the radiation hazard and reduce the weight of the unit.

Physical Appearance and Feel Method

Other than the oven dry method, most of the aforementioned means of measuring soil moisture will not be available to a Peace Corps Volunteer in underdeveloped countries.

A very common method, used by farmers and irrigation technicians alike, is the "feel or physical appearance method". This is a fairly accurate method of measuring soil moisture in the field by taking a soil sample at various depths using a soil tube or auger.

The soil auger is usually nothing more than a carpenter's auger with the screw point and side cutting edges removed. It is light in weight and easy to carry around. In soils containing fine gravel, it is frequently difficult, and sometimes impossible, to obtain samples by means of a soil auger. With a soil tube, it is sometimes possible to cut through these gravel layers and still obtain satisfactory samples. These tubes are designed so that (1) the tube can be pushed into the soil with a minimum of

effort, (2) the soil will readily enter the tube, and, (3) the tube can be easily extracted from the soil. A portion of the tube is cut away so the soil sample can be inspected when it is taken up.

After the texture of the soil has been determined, the soil sample is first "ribboned" between the thumb and forefinger. If a fairly good ribbon is extruded, soil moisture is usually above 50 percent in the heavier soils. Soils with a very small percentage of clay will not form a continuous ribbon, and the "ball" method should be used. Table 3 describes the ball forming method and the general percentage of moisture left in the soil.

Persons with some experience in irrigation soon become aware that the wetter the soil, the deeper one sinks into the mud. This observation has been used to indicate how well the soil is irrigated.

Inserting a shovel into the soil gives a better indication of soil moisture. A still better method is the use of a steel rod of about 1/2" in diameter. By pushing the rod into the soil, the depth of wetting can be determined.

These methods, while not highly accurate, are most useful where accurately calibrated instruments are unavailable.

Visual Indications of Plant Moisture Deficiency and Excess

Growth of most crops produced under irrigation is stimulated by moderate quantities of soil moisture and retarded by either excessive or deficient amounts of moisture. Air is essential to satisfactory crop growth; hence, excessive filling of the soil pore space with water drives out the air and inhibits plant growth.

On the other hand, soils having deficient amounts of water hold it so tightly that plants must exert extra energy to obtain it. If the rate of intake by the plant is not high enough to maintain turgidity of the leaves, wilting will follow. When the soil moisture content is somewhere between these two extremes, plants grow most rapidly.

A light green color in alfalfa is generally indicative of an adequate moisture supply and satisfactory growth. Among root crops such as sugar beets, a need for water is generally noted by a temporary wilting during the warm part of the day. Grain crops such as corn also will wilt temporarily when moisture is in short supply. In fruit crop production, it is not practical to wait for wilting to detect moisture requirements.

TABLE 3

GUIDE FOR JUDGING HOW MUCH MOISTURE IS AVAILABLE FOR CROPS

Available Soil Moisture Remaining	Feel or Appearance of Soil		
	Light Texture	Medium Texture	Heavy Texture
0 to 25 percent	Dry, loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily broken down into powdery condition.	Hard, baked, cracked, sometimes has loose crumbs on surface.
25 to 50 percent	Appears to be dry, will not form a ball.*	Somewhat crumbly but holds together from pressure.	Somewhat pliable, will ball under pressure.*
50 to 75 percent	Tends to ball under pressure, but seldom holds together.	Forms a ball somewhat plastic, will sometimes slick slightly with pressure.	Forms a ball, ribbons out between thumb and forefinger.
75 percent to field capacity (100 percent)	Forms weak ball, breaks easily, will not slick.	Forms a ball, is very pliable, slicks readily if relatively high in clay.	Easily ribbons out between fingers, has slick feeling.
At field capacity (100 percent)	Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand.	Upon squeezing, no free water appears on soil, but wet outline of ball is left on hand.
Saturated	Water appears on ball and hand.	Water appears on ball and hand.	Water appears on ball and hand.

* Ball is formed by squeezing a handful of soil very firmly.

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It must be remembered that plant roots will not grow into a dry soil, nor will they grow in or into a water logged soil. Application of excessive amounts of water inhibits root growth and activity. Plants develop a yellowish appearance and are unthrifty and slow growing.

TABLE 4

WATER HOLDING PROPERTIES OF SOILS

Soil Type	Moisture holding capacity in inches per foot	Amount needed to restore root zone when 50% level is reached
Clay	3.0	4.5
Clay loam	2.6	4.0
Silt loam	2.2	3.5
Silt	1.8	3.0
Sandy loam	1.5	2.5
Sand	1.0	2.0

5. EFFECT OF SLOPE ON METHOD OF WATER APPLICATION

Slope is an important factor to consider for proper control of irrigation water. On steep slopes, generally, water directed down the slope tends to channel and cause serious erosion. As the slope increases, it becomes more difficult to wet the soil without allowing an excessive amount of waste water runoff. The object of irrigation is to get water into the soil so it can be stored.

Generally speaking, clay soils have a slower rate of intake than do coarse or sandy soils. Heavy clay soils will have infiltration rates of less than 0.1 inch of applied water per hour. A coarse or sandy soil can take more than 3 inches per hour (see Table 2).

One of the more important determinations an irrigator must make is the amount of slope at which to grade his land. Table 5 shows the optimum grades or slopes for each type of soil.

TABLE 5

OPTIMUM GRADE AND MAXIMUM LENGTH OF BORDERS FOR VARIOUS SOIL TYPES

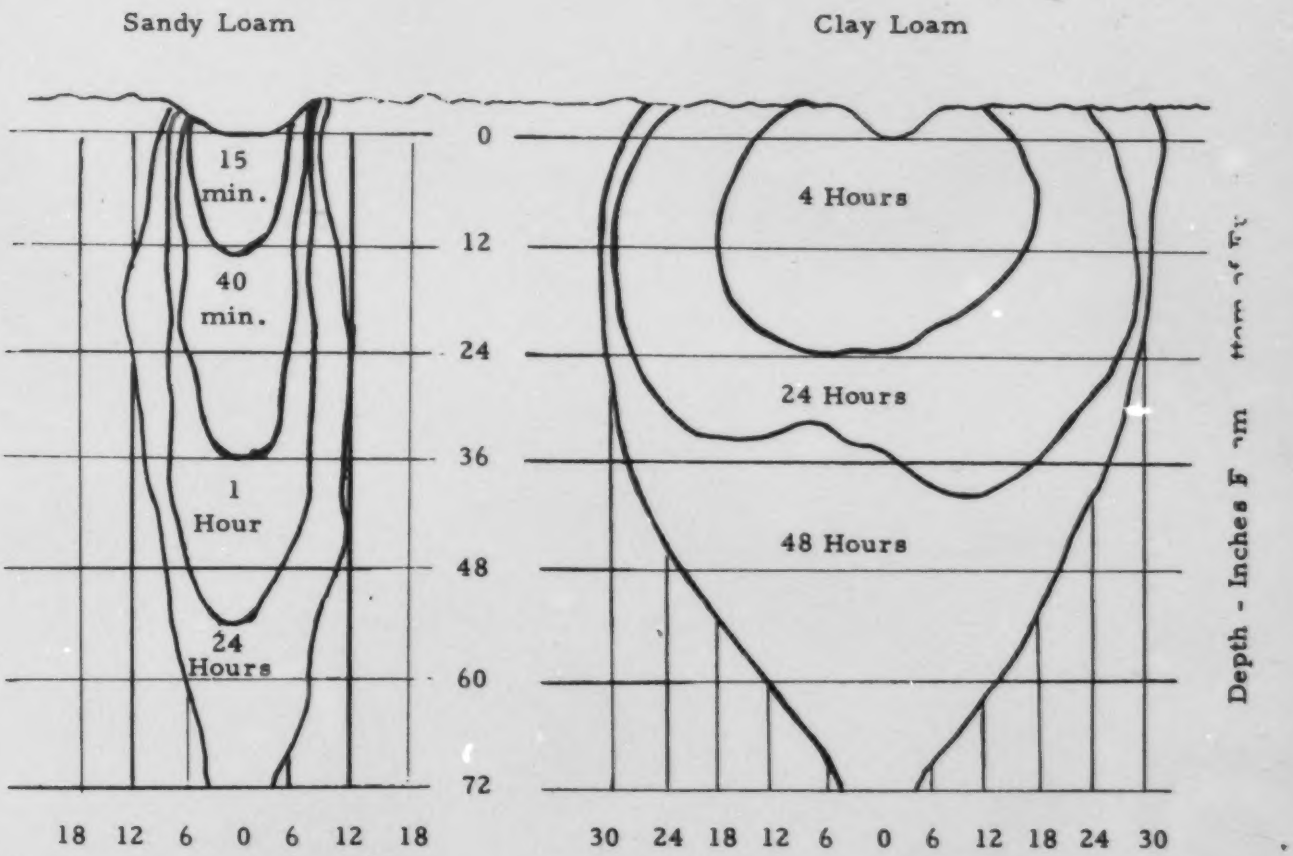
Soil Type	Optimum Grade in ft per 100 ft	Maximum Length
Clay	0.05	1,500
Clay loam	0.1	1,000
Silt loam	0.2	800
Loam (silt)	0.3	500
Sandy loam	0.4	400
Sand	0.5	300

It will be noted that on a clay soil with low infiltration rates there need be no slope or only a very slight one; on light soils the slope can be as much as 6 inches per 100 feet if the water supply is adequate and the

erosion of the soil can be controlled. The prescribed slope allows for a surface movement of water in a ratio suitable to the intake rate of the soil.

FIGURE 3

INFILTRATION OR ABSORPTION PATTERNS



Also related to the slope is the length of the border. The maximum length can be varied with each soil type. It is obvious that a short border field on a clay soil will allow the water to reach the far end and run off before the desired depth of penetration is reached. To continue

running water until penetration is complete wastes too much water in runoff at the end of the field. For this reason, level basins are recommended on heavy soils where fields are short. Conversely, a long border on a sandy soil would allow an unnecessarily deep penetration at the upper end of the strip before the water can reach the lower end. The maximum strip length, then, is directly related to the soil type, infiltration rate, and the grade of the field.

Unit Stream or Head

In irrigation there is frequent mention to the "unit stream" or "unit head". The unit stream is the water application in CFS (cubic feet per second) for each foot of width of the border strip per 100 feet of length. Simply stated, it is the amount of water needed per 100 square feet of irrigated field. The ability to manage water, soil, and crops must be based on the irrigator's knowledge of the water supply he has at his disposal in relation to the field he wishes to irrigate.

Unit stream is the amount of water needed based on the soil infiltration rate, slope of the land and effective root zone for crop production. There are charts that can be used to calculate this. Table 6 gives the unit streams necessary for combinations of depths of irrigation and intake rates of various soils. To use the table, determine to what depth moisture should be replaced. Then find the unit stream in the appropriate column for the applicable infiltration rate. These figures are accurate for slopes between 0.3 and 0.5 percent. On heavy soils with flatter slopes, the unit stream should be increased by about 5 percent.

Using Table 6, one can find the rate of water in CFS needed for each foot of width of the border for each 100 feet of run. For instance, if the border is 25 feet wide and 300 feet long and a 3 inch depth of water is desired on a soil with a 1 inch per hour final intake rate, the unit stream is found to be .01 CFS. To determine the rate of water needed, the following formula is used:

$$(1)\quad \text{Border Stream} = \text{Unit Stream} \times \frac{\text{Length (ft)}}{100} \times \text{Width (ft)}$$

$$\text{or} = .01 \times \frac{300}{100} \times 25 = .75 \text{ CFS}$$

Conversely, if the rate of water is known, the width of the border can be computed by a transposition within the same formula:

$$(2)\quad \text{Width (ft)} = \frac{\text{Border stream} \times 100}{\text{Unit stream} \times \text{Length (ft)}}$$

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TABLE 6

UNIT STREAMS FOR VARIOUS DEPTHS OF IRRIGATION ON SOILS OF DIFFERENT FINAL INFILTRATION RATES

Depth of Watering	Final Infiltration Rate in Inches Per Hour													
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5	2.0	2.5	3.0
1"	.0018	.0037	.0055	.0074	.009	.011	.013	.015	.017	.018	.028	.036	.045	.055
2"	.0014	.0027	.004	.0054	.0067	.008	.0095	.011	.012	.013	.02	.027	.034	.04
3"	.001	.002	.003	.004	.005	.006	.007	.008	.009	.010	.015	.020	.025	.030
4"	.00074	.00015	.0022	.003	.0037	.0044	.0052	.0059	.0066	.0073	.012	.015	.018	.022
5"	.00055	.0012	.0017	.0022	.0027	.0033	.0038	.0044	.005	.0055	.0082	.011	.014	.017
6"	.0004	.0008	.0012	.0017	.002	.0024	.0028	.0032	.0036	.0041	.006	.008	.01	.012

For any given soil type and depth of irrigation, there is but one unit stream. The total quantity of water needed will vary with the size of the border strip to be irrigated.

For ease in computing the amount of water needed for various soils at the time they need irrigation and for the optimum length and width of borders, Table 7 is included. It can be seen that for each soil type and its individual water needs, the total water required for a 25 foot wide strip of land in maximum lengths varies greatly from clay to sandy soils.

TABLE 7

AVERAGE UNIT STREAMS AND BORDER STREAMS
FOR VARIOUS SOIL TYPES

ıe	Optimum Length of Border	Average Final Intake Rate Inches Per Hour	Average Depth of Irrigation Inches	Unit Stream	Border Stream for 25 Foot Border of Optimum Length (CFS)
	1,500	0.1	4.5	.00065	0.243
n	1,000	0.2	4.0	.0015	0.375
	800	0.5	3.5	.0043	0.86
	500	1.0	3.0	.01	1.25
ım	400	2.0	2.5	.023	2.3
	300	3.0	2.0	.04	3.0

It will be noted that a clay soil having a border strip area of ess than one acre will require a delivered stream at the border :FS to give a 4-1/2 ch irrigation. At the other end of the soil .e sandy soil with [illegible] res will require a border stream of to give adequate and uniform irrigation. It is important that the ıt of water across the land surface be matched with the soil te. If the size of the field is reduced, the border stream can ed. The unit stream remains constant. To get the penetration ıture storage needed, a definite time period must be allowed to

elapse so that water can soak into the land. A too short contact period will mean too little water has entered the soil moisture reservoir. Too long periods of water application will encourage deep penetration losses.

Using the figures in Table 6, the unit stream on a sandy soil with a final intake rate of 3 inches per hour for a 2 inch water application, will be .04 CFS. Using formula (2) on a 300 foot long field and with one-half CFS of water available, the designed width of the border should be:

$$W = \frac{.5 \ (100)}{.04 \ (300)} = 4 \text{ feet}$$

Thus, on a sandy soil with only one-half CFS discharge, the farmer must not have borders wider than four feet. Otherwise, he will be applying water inefficiently and the water wasted by deep percolation will build up an unfavorable water table. Table 8 shows the border widths that must be designed for borders of various length with one-half CFS discharge at the field.

TABLE 8

DESIGNED BORDER WIDTHS FOR VARIOUS SOILS
WITH VARYING LENGTHS OF BORDERS
USING 0.5 CFS IRRIGATION STREAM

Soil Type	Optimum Length of Border (ft)	Average Final Intake Rate (in/hr)	Inches of Water Needed	Unit Stream	Border Width (ft)
Clay	1,500	0.1	4.5	.00065	51
	1,000	0.1	4.5	.00065	77
	500	0.1	4.5	.00065	150
Silt	700	1.0	3.0	.01	7
	500	1.0	3.0	.01	10
	300	1.0	3.0	.01	17
Sand	400	3.0	2.0	.04	3
	300	3.0	2.0	.04	4
	200	3.0	2.0	.04	6

Using the above formula with results as shown in Table 8, it is apparent that even on a silt type soil the border strip must not exceed 17 feet in width if it is about 300 feet long. A longer field will mean an even narrower one.

From Table 8 it can be seen that one-half CFS discharge is more than adequate on heavier clay type soils. In the case of clay, the one-half CFS could irrigate six 25 foot border strips simultaneously. On light or sandy soils, one-half CFS is too small a stream to do an efficient job of irrigating.

In actual practice in developing countries, most farmers irrigate an entire field of from one to three acres without borders to help control the water. It does not require too great an imagination to see how inefficient such irrigation methods are and what a great waste of water results. One can visualize each field as a form of border strip and superimpose the figures from Table 8 on them. The result is always the same--small flows on large field areas result in deep penetration losses and limited area coverage. Such inefficient irrigation is a direct cause of waterlogging and salt buildup and increases the drainage requirements of the project.

The length of time which water flows over a field has a direct bearing on the amount of water that goes into the soil. The chart figuring the unit stream is based on the assumption that water can be shut off or moved to another strip at the time it reaches the far end of a border of any length. While it may be more efficient to use the maximum lengths, often the size of the field cannot be changed. This is one point at which an irrigator loses some flexibility when he designs a system.

This loss of flexibility can be offset by the application of formula (2) if the width of the strip is changed to compensate for its short run. If the formula is followed and the system designed according to the tables and charts, the time element will take care of itself. When the water reaches the far end of the strip, it is shut off and moved to another strip.

Another formula that is useful to anyone who designs an irrigation system is:

$$T = \frac{15\,(D)}{I}$$

T is the time of irrigation (expressed in minutes); D is the depth of watering necessary; and I, the final intake rate of the soil. This formula is for level borders with intake rates up to 1 inch per hour. On graded borders with intake rates in excess of 1 inch per hour, the formula is:

$$T = \frac{60}{I}$$

Again, using the various soil types with their known intake rates, when the amount of water needed to replenish the soil reservoir to field

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capacity is found, the time needed to irrigate the soil to that depth desired can be determined by the above formula.

Table 9 gives a compilation of the time needed by classification of soils when they have reached 50 percent of field capacity moisture level.

Actually it is in this table that we find the reason for low production on lands not waterlogged and on which most other farm management practices appear acceptable. Some farmers never give any consideration to the matter of the period of water application. Two extremes are practiced: In one, the field may be bounded and water may stand on the field for two to three times as long as necessary; this is wasteful of water and harmful to many crops. The other is wild flooding where the water is pushed and directed to various spots on the field and few places get water for more than a few minutes; penetration is shallow in such cases and irrigation is of little value. Often such shallow irrigation results in shallow roots which allow plants to die as soon as they are subjected to an ordinary period of drought.

TABLE 9

TIME REQUIRED TO REPLENISH SOIL MOISTURE
WHEN 50 PERCENT OF FIELD CAPACITY HAS BEEN REACHED

Soil Type	Average Intake Rate - Inches Per Hour	Depth of Irrigation Needed in Inches	Time*	
Clay	0.1	4.5	11 hrs. 15 min.	(1)
Clay loam	0.2	4.0	5 hrs.	(1)
Silt loam	0.5	3.5	1 hr. 45 min.	(1)
Silt	1.0	3.0	3 hrs.	(2)
Sandy loam	2.0	2.5	1 hr. 15 min.	(2)
Sand	3.0	2.0	40 min.	(2)

* From formula

(1) Using level border formula (2) Using graded border formula

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6. IRRIGATION EFFICIENCY

Water is a very precious resource and no man has the right to waste that which another can use. Efficient use of irrigation water is an obligation of every user. Efficiency is influenced by cost and quality of labor, ease of handling, crops being irrigated, and soil characteristics. Adequate control and management of irrigation water require that methods be available to evaluate irrigation practices from time to time.

Water conveyance or delivery losses must be the first evaluation. These are recognized by the engineer when the system is designed. Having conveyed the water to the farm, the need to apply the water efficiently becomes apparent. Often considerably more water is applied to the soil than it can possibly hold. In normal irrigation practices, surface irrigation efficiencies of application are in the range of 45 to 50 percent, whereas, well-designed sprinkler irrigation systems are generally considered to be about 75 percent efficient.

Neglecting evaporation losses during the time water is being applied, efficiency of use can be calculated thus:

$$Ea = \frac{100\ Wf - (Rf + Df)}{Wf}$$

when: Ea = water - application - efficiency

Wf = water delivered to the farm

Rf = surface runoff

Df = deep percolation below root zone

At each irrigation, the farmer applies a given amount of water to his land with the intention of storing the water in the root zone of his soil. Of course, he cannot store it all. The loss of some water is unavoidable. The most common losses of irrigation water are represented by runoff and deep percolation. This is brought on by:

1. Irregular land surfaces
2. Shallow soils underlain by gravels of high permeability
3. Improperly designed distribution systems

4. Non-attendance of water during irrigation

5. Excessive single applications

6. Improper preparation of the land

Water storage efficiency becomes especially important whenever insufficient water is stored in the root zone during a single irrigation. The depth of water applied during each irrigation is a dominant factor influencing efficiency of application. Many variable factors such as land uniformity, irrigation method, size of irrigation stream, length of run, soil textures, permeability, and depth influence the time the irrigator keeps water running.

Consumptive Use and Evapo-Transpiration Ratio

Consumptive use, or evapo-transpiration, is the sum of two terms: (1) Transpiration, which is water entering plant roots and used to build plant tissue or being passed through leaves of the plant into the atmosphere; (2) Evaporation, which is water evaporating from adjacent soil, water surfaces, or from the surfaces of leaves of the plant. Consumptive use can apply to water requirements of a crop or a farm, hence the term "consumptive use".

The volume of water transpired by plants depends in part on the water at their disposal, and also on temperatures and humidity of the air, wind movements, intensity and duration of sunlight, stage of development of the plant, type of foliage, and nature of the leaves. During the growing period of the plant, there is a continuous movement of water from the soil into roots, up stems and out of the leaves of the plants. A very small proportion of the water absorbed by the roots is retained by the plant. When the rate of transpiration exceeds the rate of absorption by the roots, wilting occurs.

Evaporation losses from the soil vary with the amount of water able to reach the surface by capillary action. Where irrigation water is applied by flooding methods, large amounts of water are lost by direct evaporation from soil surfaces without having passed through the plant. After light showers during the growing season, considerable moisture is retained on the leaves where it evaporates. A wide furrow spacing and considerable exposed ground surface may result in excessive surface evaporation.

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Effect of Climate on Consumptive Use

Variations in consumptive use occur from day to day because of changes in weather. A hot, dry, windy day will increase the rate; whereas, a cool day will decrease the rate of consumptive use. Because of many variables, means of characterizing the effect of climate on evapo-transpiration are highly inadequate. Exposure, height and color of the leaf surface are all important.

Table 10 shows some consumptive use figures for various irrigated crops. These are average figures but should be within ten percent of the requirements for most areas.

TABLE 10

CONSUMPTIVE USE OF WATER BY MAJOR IRRIGATED CROPS UNDER SEMI-ARID CONDITIONS
(In Inches Per Acre)

Crop	Average Daily Use	Mean Monthly Consumptive Use	Peak Use Per Day at Flowering Stage	Seasonal Consumptive Use
Wheat	0.13	4.0	.25	17.0
Paddy Rice	0.23	7.0	.32	35.0
Sugar Cane	0.30	9.0	.45	110.0
Cotton	0.20	6.0	.28	30.0
Potatoes	0.13	4.0	.22	19.0
Beets-Sugar	0.25	7.0	.30	40.00
Corn	0.17	5.0	.25	25.00
Grain Sorghums	0.13	4.0	.20	20.00

It can be seen from the above Table that the peak use of most crops is quite high. Wheat has a peak use period from the late flower through the soft dough stage. During that time, wheat must have 1/4 of an inch of water per day for satisfactory yields. It is a simple mathematical procedure to

determine how often one has to replenish a given amount of water in the soil. *Table 11 shows* again the soil types, the amount of water needed to bring the soil moisture from 50 percent up to field capacity, the peak consumptive use per day, and the frequency of irrigation needed. It would not do to over irrigate heavier clay type soils with the idea that one can reduce the frequency. The soil will hold only so much water and no more. Water in excess of 100 percent of field capacity will be lost to the lower strata of the soil and may build up a water table.

There are no averages, as for instance, water application every 20 days, in the specifics of irrigation. One can find averages, but farmers should not be bound to them. Soils vary, crops vary, dates of seeding vary, and methods of seeding and methods of irrigation differ with the size and shape of the field. The most important factors are the soil moisture retention capacity, depth of root zone, and crop consumptive use. To do an adequate job of irrigating, the soil, crop, and water must be closely interrelated.

TABLE 11

FREQUENCY OF IRRIGATION OF WHEAT

Soil Type	Inches of Water Needed	Peak Use Per Day Acre Inches	Days Between Irrigations
Clay	4.5	.25	18
Clay loam	4.0	.25	16
Silt loam	3.5	.25	14
Silt	3.0	.25	12
Sandy loam	2.5	.25	10
Sand	2.0	.25	8

UNIT B - WATER MEASUREMENT

Correct application of irrigation water is of the utmost importance. First, the crops should be supplied with an adequate amount of moisture. Under irrigating can severely affect crop yields. Over irrigating must also be avoided as a matter of economics as well as erosion control. Increased use and value of available water, in areas of short supply or where the use of available water has not been developed, makes an understanding of the methods of water measurement necessary.

Much information has already been presented in regard to water requirements for plant growth. This information cannot be effectively utilized without the measurement of water. Oftentimes, a certain amount of water must be divided among multiple users on a common supply ditch. Some form of measurement must be employed to be able to regulate the amount of flow to each party.

Methods

There are many methods employed in measuring of water. However, certain terms should become familiar before any of these methods are discussed.

There are two units used in measuring water--volume and flow rates. The following are the basic units used for most calculations:

1. 1 acre inch = 27,154 gallons, or 3,630 cubic feet of water. This is the amount of water required to cover 1 acre to a depth of 1 inch.

2. 1 acre foot = 325,850 gallons, or 43,560 cubic feet of water.

3. 1 cubic foot = 7.48 gallons, or 1,728 cubic inches, or 62.37 pounds of water.

4. 1 cubic foot per second = 448.8 gallons per minute (gpm)

5. 450 gpm = 1 acre inch per hour (approximate)

6. gpm x 0.002228 = cubic feet per second

$$\frac{\text{Pump discharge in gpm}}{450} = \text{acre inches per hour}$$

$$\frac{\text{Total acre inches pumped}}{\text{Number acres covered}} = \text{average depth applied in inches}$$

Irrigation efficiency must also be considered when making irrigation calculations. This is, simply, the amount of water that reaches the root zone stated as a percentage of total water applied. Losses from evaporation, deep percolation and runoff can be quite high. There is no exact formula for determining field efficiency that will work in every instance. Field tests can be run to determine how much water must be applied to get given quantities into the root zone area of the soil. A 60 percent field efficiency is a practical goal.

Floating Marker

A very simple method, but one that does not give a high degree of accuracy in measuring the rate of flow, is the "floating marker" estimate. It is useful when more costly installations are not warranted or complete accuracy required. A relatively straight section of ditch with a fairly uniform cross section is selected. The length of ditch (generally between 50 or 100 feet) will depend on the current. Make several measurements of depth and width within the trial section to arrive at an average cross section area in square feet. Stretch a string or tape across each end of the section at right angles to the flow. Place a small float in the ditch, a few feet upstream from the start of the trial section. Record the time required for the float to pass through the measured section. Make several trials to arrive at an average speed.

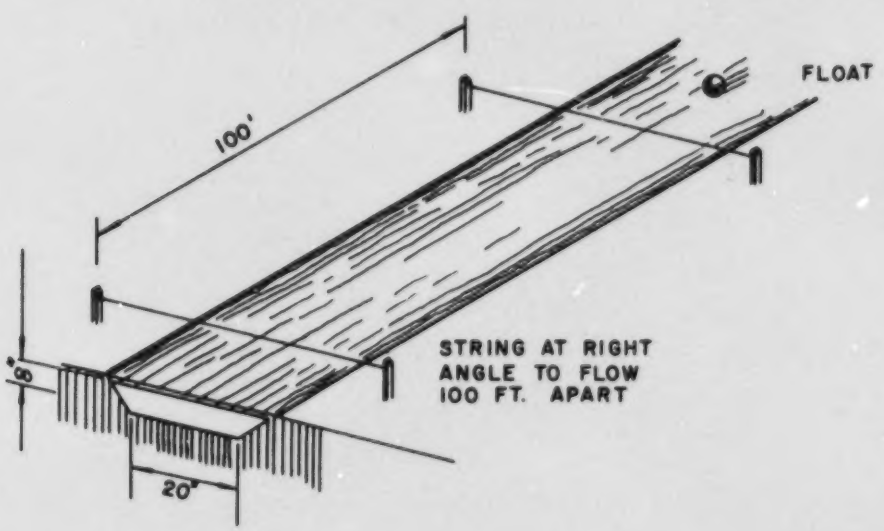


FIGURE 4

Calculating the flow of water using the float method.

To calculate the velocity in units of feet per second, divide the length of the section (in feet) by the time (in seconds) required for the float to travel that distance. Since the speed of the float on the surface of the water will be greater than the average velocity of the water, a correction factor, usually .80, is used.

To obtain the rate of flow, multiply this average velocity (measured velocity x .80) by the average cross sectional area.

$$\frac{\text{Length of trial ditch}}{\text{Time in seconds}} \times .80 \times \text{cross section area} = \text{rate of flow}$$

Weirs

This method makes use of a specially built construction of known dimensions. A weir is a notch of regular form through which water may flow. They are classified according to the shape of this notch. Examples of weirs are: the Rectangular Contracted, the V-Notch, the Cipolletti, and the Rectangular Suppressed.

The weir, when properly constructed and installed, is one of the simplest as well as most accurate methods of measuring water. Under ideal conditions it will be accurate within two to three percent. Under most field conditions, accuracy within five to fifteen percent can be expected. By following simple instructions, a weir can be easily constructed and installed:

1. Set the weir structure in a channel that is straight for a distance upstream from the weir equal to at least ten times the length of the weir crest.

2. Place the weir at right angles to the direction of water flow.

3. Make sure the face of the weir is exactly vertical and the crest level so the depth of water is the same at all points.

4. There should be no obstructions on the upstream side of the weir.

5. The crest of the weir should be sharp--not more than one-eighth of an inch in thickness--so that the water passing over it will touch at only one point.

6. Water should not approach the weir at a speed over .5 foot per second. This may be accomplished by setting the weir at the end of a long pool that is fairly wide and deep.

7. The height of the crest of the weir above the bottom of the channel should be at least twice and preferably three times the depth of the water flowing over the crest.

8. The distance from the sides of the weir notch to the side of the channel should be at least twice the depth of the water flowing over the crest.

9. The length of the weir crest should be so constructed that the head to be measured exceeds two inches and the maximum head, preferably, is not greater than one-third the length of the weir crest.

10. The weir should be constructed in such a manner that the water will fall freely below the weir, leaving an air space under the over-falling sheet of water. Lack of adequate air space under the sheet of falling water will cause a suction, drawing down the water surface and increasing the discharge.

11. To prevent erosion, the ditch downstream should be protected by loose rock, cement construction or the like.

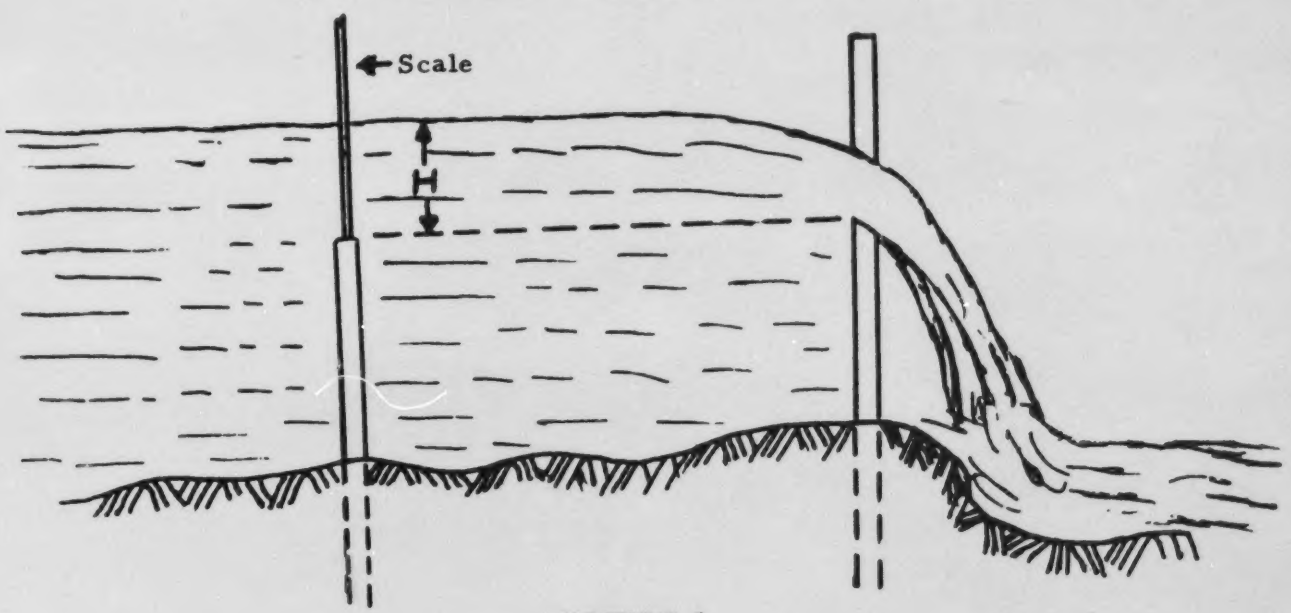


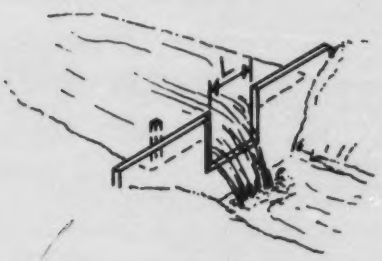
FIGURE 5

Measuring a head on a weir. Measure upstream from downward curve of the water surface.

The head of water is measured upstream from the crest where the surface drawdown curve does not affect the measurement. This should be done at a point upstream at least six times the depth of the head on the weir. A stake driven into the pool this distance upstream from the weir, with its top level with the weir crest, will make for easy observations.

Rectangular Contracted Weirs

This weir takes its name from the location and shape of the opening through which the water flows. It was one of the earliest forms developed, but because of its simplicity, ease of construction, and accuracy, it is still one of the most popular.



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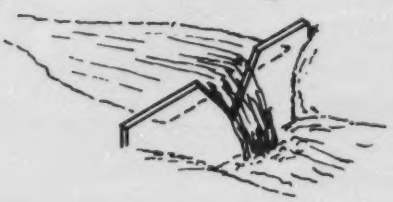
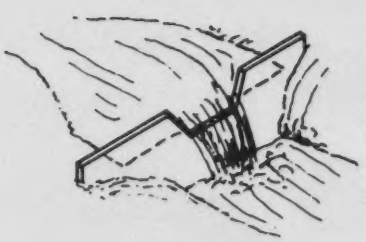


V-NOTCH



CIPOLLETTI

WEIRS

FIGURE 6

V-Notch Weirs

The 90 degree triangular, or V-Notch weir, has a greater practical range of capacity than other types. This type weir should not be used when substantial head loss cannot be tolerated. Its shape makes it very easy to construct and it is very accurate at low flows.

Cipolletti Weirs

In this trapezoidal weir, the sides have a slope of one horizontal to four vertical. It is widely used because the discharge is believed to be directly proportional to the length of the weir crest.

Appendix Tables II, III, and IV give the flows for these weirs in cubic feet per second and gallons per minute.

Parshall Flume

Because of several distinct advantages, the Parshall Flume is being used quite widely. It is self-cleaning, requires only a small amount of drop or head loss in the stream, and permits quite accurate measurement. The discharge is obtained by measuring the loss in head caused by forcing a stream of water through a throat with a depressed bottom. Since the size of the head is small upon which measurements are based, care should be taken in determining the differences of water level. The flumes also have to be constructed with specific dimensions and the measurements taken at designated points.

Trajectory Method

This method determines the rate of flow discharging from the end of a pipe. Knowing the dimensions of the pipe, the trajectory of the water is measured as it emerges from the pipe. These figures are then applied to the appropriate tables to determine the rate of flow in gallons per minute.

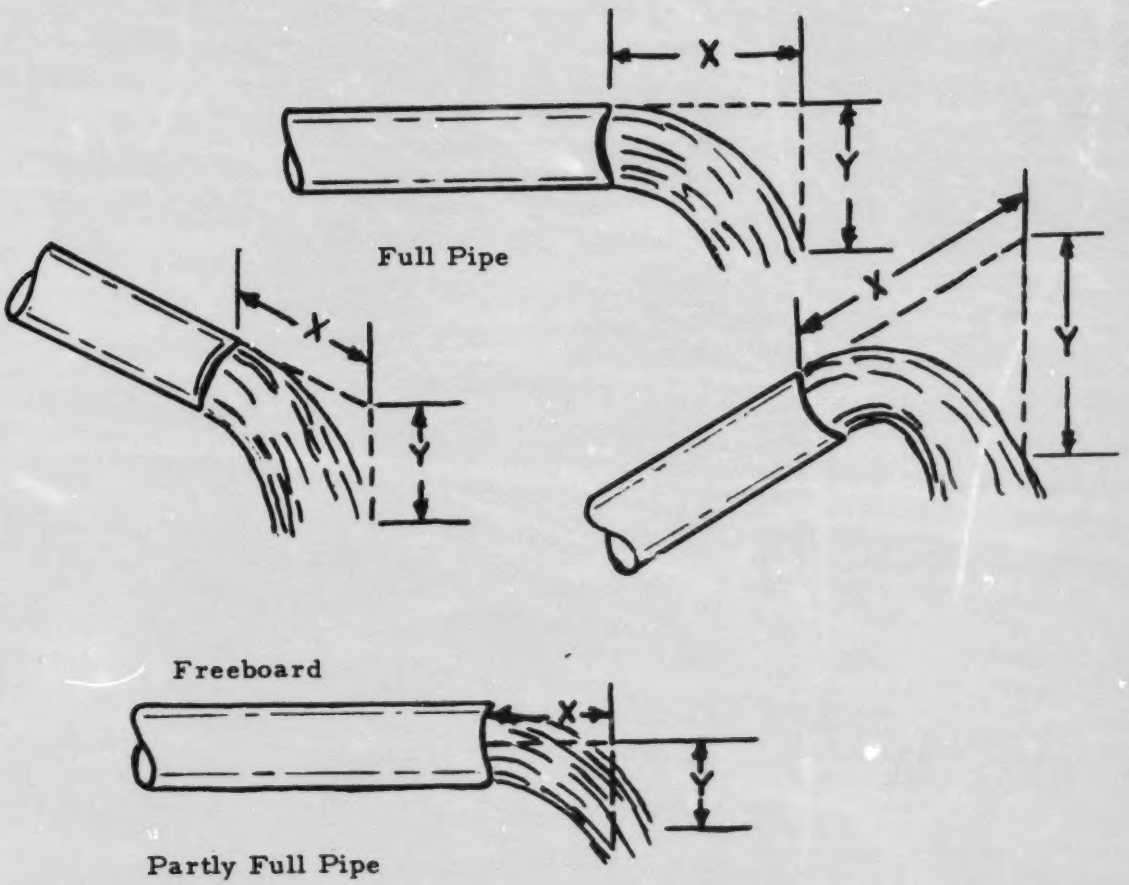
Water Flowing Through Pipes

A number of devices have been manufactured to give accurate measurements of water flow through a pipe. Among these are the Venturi Tubes, the Collins Flow Gage, and the Cox Flowmeter. Since most of these measure the velocity at only one point in the cross section of the pipe, there are different procedures for obtaining the mean velocity. The simplest method is to measure the velocity at the center of the pipe where

velocity is the highest and apply a coefficient to find the mean velocity. Precise measurements are not possible with this method.

The dye method is good for determining velocities in pipe lines. A small quantity of the dye solution is injected into the water at the intake of the pipe line or at some point along the line. The time at the instant the coloring matter is introduced and at its first and last appearance at the second point of observation, usually at the outlet of the pipe, is noted. From the time data and length between points, the velocity of flow is computed.

Velocity or current flow meters are often employed on water lines. It is a small instrument containing a revolving wheel or vane that is turned by the current. If calibrated correctly, these instruments have the added advantage of eliminating computations in volume determinations. Meters subject to clogging should never be used on pipe lines receiving water from open ditches.



Note: Unless pipe is full or nearly so, measure ordinates on mid-line of jet as shown.

FIGURE 7

How To Measure Pipe Flows

TABLE 12

DISCHARGE FROM PIPES FLOWING FULL
In Gallons Per Minute with Vertical Drop "Y" = 13 Inches

Pipe Size		Horizontal Distance "X"						
Inside Diameter	Sq. In. Area	12"	14"	16"	18"	20"	22"	24"
2"	3.14	38	44	50	57	63	69	75
2-1/2"	4.91	59	69	79	88	98	108	118
3"	7.07	85	99	113	127	141	156	170
4"	12.57	151	176	201	226	251	277	302
5"	19.64	236	275	314	354	393	432	471
6"	28.27	339	396	452	509	565	622	678
7"	38.48	462	539	616	693	770	847	924
8"	50.27	603	704	804	905	1,005	1,106	1,206
9"	63.62	763	891	1,018	1,145	1,272	1,400	1,527
10"	78.54	942	1,100	1,257	1,414	1,571	1,728	1,885
11"	95.03	1,140	1,330	1,520	1,711	1,901	2,091	2,281
12"	113.10	1,357	1,583	1,809	2,036	2,262	2,488	2,714

TABLE 13

APPROXIMATE FLOW FROM PARTIALLY FULL PIPE
Rate of Flow in Gallons Per Minute

Y	Inside Diameter of Pipe "D" in Inches				
D	4	6	8.	10	12
0.1	142	334	579	912	1,310
0.2	128	302	524	825	1,185
0.3	112	264	457	720	1,034
0.4	94	222	384	605	868
0.5	75	176	305	480	689
0.6	55	130	226	355	510
0.7	37	88	152	240	345
0.8	21	49	85	134	194
0.9	8	17	30	52	74
1.0	0	0	0	0	0

UNIT C - IRRIGATION WATER CONTROL

A well designed irrigation system delivers the required amount of water to all parts of the area to be irrigated at the required rate without damage to the soil or excessive loss of water. It is accessible and easy to operate without obstructing other farming operations. Many factors affect the design of such an irrigation system. Such factors as soil, crop to be irrigated, topography, water supply, existing facilities, etc., should all be studied carefully.

1. WATER REGULATION IN DELIVERY CHANNELS

Conveyance of the water from the source to the field is of primary concern. Irrigated lands are often located great distances from the source of their water supply. Depending on its source, water is sometimes conveyed several hundred miles to its area of use. The quantity of irrigation water required for any particular period should equal or exceed the gross irrigation requirement for that period. To this amount should be added any water required for leaching, temperature control, or frost control.

In addition to the total amount of water required, rate of delivery is an important factor in designing and operating an irrigation system. Irrigation water must be made available to each part of the farm irrigation system at a rate and elevation that permits proper operation of the selected methods of water application. Irrigation water must be conveyed as economically, efficiently, and reliably as possible.

Conveyance facilities generally are either open ditches with all the necessary structures or closed conduits. They must be accessible for operation and maintenance. Ditches that carry irrigation water from the source of supply to one or more farms are known as canals or laterals. They are generally large and usually permanent installations. Field ditches convey water from the source of supply to a field or fields within the farm unit. They also should be permanent installations. Head ditches are used to distribute water in a field for surface irrigation. They are laid out at the high end of the irrigation run and are generally perpendicular to the direction of irrigation. Head ditches can be permanent or reconstructed each year.

Ditches work best in clay or clay loam soils since seepage is usually less and ditch banks are more stable. Open ditches can carry large volumes of water and have a low cost per volume of water carried. They do have some disadvantages if unlined. Losses from seepage and evaporation can be high, weeds and animals can cause trouble, and they take up valuable space.

2. WATER REGULATION IN FIELD CHANNELS

Distribution control structures are required for easy and accurate distribution of water to various fields on the farm. Selecting the proper kind of water control structure and locating it properly is an important part of planning a farm irrigation system.

Headgates

A check or headgate is built across laterals and ditches for the purpose of diverting part or all of the stream. Its function is to regulate the quantity of water flowing into the small lateral, the field ditch, or the furrow. The amount of opening in the check gate regulates the amount of water turned into the field. This is done one of two ways; mechanically, by means of a screw or a series of gears, or by inserting or removing wooden boards to increase or decrease the opening in the headgate.

TABLE 14

A guide to the approximate amount of water that can pass through a certain size gate opening assuming a range of velocity from 1.5 to 3.0 feet per second.

Gate Frame	Flow Capacity	
	cfs	gpm
18 x 12	1.0 - 2.0	450 - 900
18 x 18	2.0 - 4.0	900 - 1,800
24 x 12	1.5 - 3.0	675 - 1,350
24 x 18	3.0 - 6.0	1,350 - 2,700
24 x 24	4.5 - 9.0	2,050 - 4,050
30 x 18	3.5 - 7.5	1,575 - 3,375
30 x 24	5.5 - 11.0	2,475 - 4,950
30 x 30	7.5 - 15.0	3,375 - 6,750
36 x 24	6.5 - 13.5	2,950 - 6,075
36 x 30	9.0 - 18.0	4,050 - 8,100
36 x 36	11.0 - 22.5	4,950 - 10,125
42 x 42	15.5 - 31.0	6,975 - 13,950
48 x 36	15.0 - 30.0	6,750 - 13,500
48 x 48	21.0 - 42.0	9,450 - 18,900
60 x 48	26.0 - 52.0	11,700 - 23.400
72 x 48	31.5 - 73.0	14,175 - 28,350

An important feature is to set the posts of the structure to a depth of at least three feet to hold the structure firmly in place. It is also important to build cut off walls and wing walls sufficiently into the bed of the canal to prevent washing under the structure.

Checks

Checks consist of only a single wall built at right angles to the stream or canal. A notch through the center provides a passage for the water when not in use. Grooves in the wall, into which flashboards can be fitted, provide for checking or raising the water surface when desired for diversion.

To protect the channel against erosion, a heavy rip-rapping of rocks should be placed on the lower side. Sufficient cement should be used to make a durable structure. Too much economy in the mixture or in the dimensions of the structure may result in total loss.

3. DITCHES AND DELIVERY STRUCTURES

Metal tapoons are often used as checks in distribution ditches. These can be used with fair accuracy to measure the flow of water as well as to divert it. Because of the weight involved, they are not usually used in streams delivering more than five cubic feet per second as they become too burdensome to carry about the field. These checks are usually forced into the sides and bottom of a ditch on a slant and held in place by the weight of the water. Equipped with an adjustable weir-type gate, they can be used for measuring of water since the opening through which water passes has fixed dimensions.

Portable metal dams are used successfully for small ditches in soils that do not erode readily. They consist of a half circle or triangle shaped piece of heavy gauge metal, reinforced across the top and usually with a single metal rod through the center that is forced into the bottom of the ditch.

Canvas and plastic dams are used to divert streams as large as eight CFS or more, although streams of two to three CFS are more commonly diverted by using these portable dams. A heavy, durable canvas or plastic is necessary to stand the water pressure and prevent excessive leaking.

This type of dam should measure about four feet wide and six feet long, but may be larger for larger ditches. The six-foot side is fastened to a ten-foot 2 x 2, 2 x 4, or a pole which may or may not be hinged in the middle, depending on whether some water is to be allowed to bypass.

This kind of check is usually put into place before the water reaches the point of diversion. It is laid in the ditch with the canvas extending upstream and the pole spanning the ditch and resting on each bank. Some soil should be thrown on the edges of the dam to hold it in place.

If the pole is hinged in the middle, the plastic or canvas check becomes a bypass dam. By enlarging or reducing the angle, more or less water is allowed to flow over the dam. It is possible in this way to divert water onto the land and at the same time permit some to flow past the diversion to lower sets in the field. The same action can be acquired by using a sack arrangement on a canvas dam, in which the opening of the sack is enlarged or reduced to allow water to flow past. This type of arrangement is particularly suited to the irrigation of row crops where

siphon tubes or spiles are used as turnouts and the water level in the ditch must be held at a uniform level to operate them.

It is often necessary to build dams and checks from inexpensive and local materials to divert streams. A structure using alternate layers of rock, brush and native logs may be built with little if any cash outlay. The dam is built by placing alternate layers of rocks and brush, backed up with earth fill, with each layer set back to give a stairway effect to the spillway. The general slope of the fill on both sides of the dam should be two feet of run to one foot of rise.

The crest or top of the dam should be built high enough to divert the correct amount of water when the stream is low. The diversion channel should be protected with a headgate so that the amount of diverted water may be controlled. At the lower end of the spillway, the channel should be heavily rip-rapped the full width for a distance of four to six feet. The headwall, sidewalls, and wing walls are constructed of logs, notched and tied together at the corners for strength.

This type of structure is to be recommended wherever brush, rocks, and logs are available convenient to the site. Since these materials are cheap, they should be used in liberal proportions.

Drops

Drop spillways or pipe drops control ditch velocity by lowering the water abruptly from one level to a lower level. Because of the erosion hazard on excessive slopes, drop structures are installed to alleviate continuous deepening of the channel. These drops can be and often are built into a check or division box.

A drop spillway is a weir. Water flows through the weir opening in the headwalls, drops to a nearly level apron spilling basin or to a lower level, and then flows into the downstream section of the channel. For small drops, a simple apron usually is adequate (see Figures 8 and 9). For higher drops or bigger streams, some type of energy dissipater must be provided. Dimensions for these types of drops are given in Table 15.

Large open drops are usually built of reinforced concrete. Smaller drops can be made of concrete, rock masonry, rot-resistant lumber, or steel and aluminum treated against corrosion.

A pipe drop is a section of pipe with a riser equal to the required drop. A fill must be built across the ditch to direct water through the pipe.

Corrugated metal pipe drops are frequently used as are discarded oil barrels with both ends removed and welded end to end until the desired length is achieved. Pipe drops are especially suited to small ditches. The fill across the ditch may be widened by adding extra pipe so that a road crossing is provided if needed. Pipe drops are more easily plugged by trash than are weirs. Earth fills around pipe drops should be inspected frequently to protect against damage by burrowing rodents.

Small temporary drops under very small stream flows can be built into temporary ditches by using a plastic liner to lower the water from one elevation to another. Frequent inspections should be made to make sure the lining is kept in place and is not punctured. On larger flows, the plastic should be covered with gravel. All vegetation, rocks, and other abrasive materials should be removed from the area on which the plastic is to be placed.

TABLE 15

DIMENSIONS OF DROP STRUCTURES IN RELATION TO DITCH CAPACITY

Capacity of Ditch in CFS	Width of Opening (W) Ft.	(H) In.	(C) In.	(A) (B) (E) & (F) Ft.
2	1	12	6	2
6	2	12	6	2
8	2-1/2	15	6	2
10	3	18	8	2-1/2
14	3-1/2	18	8	3

Drop (D) Feet	Length of Apron (L) Feet
1	2-1/2
1-1/2	3
2	4
3	6

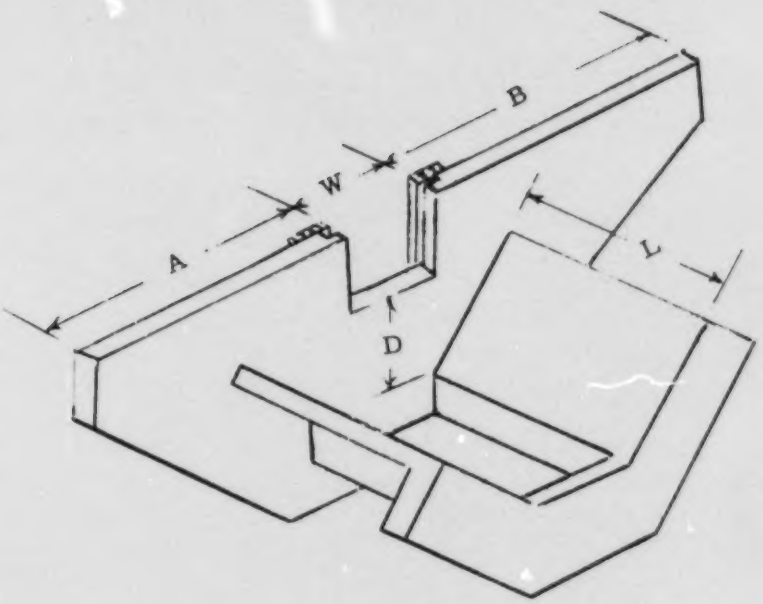


FIGURE 8

Concrete Drop For Farm Head Ditches

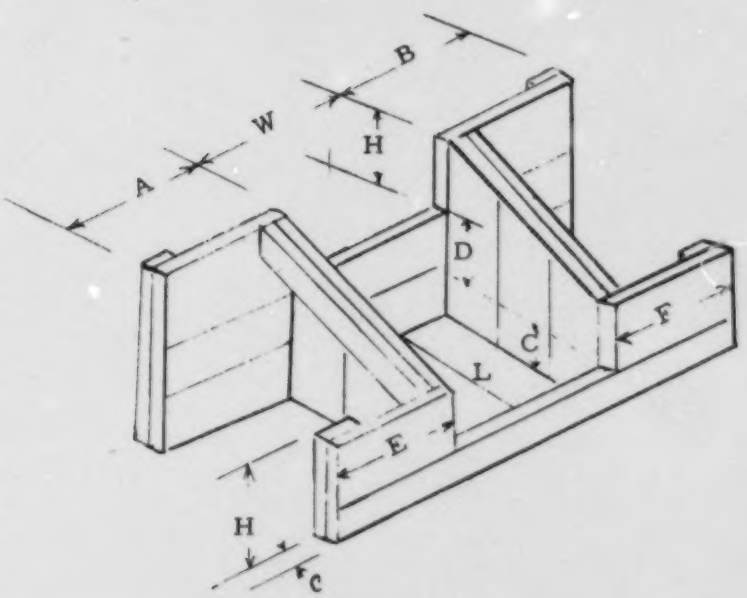


FIGURE 9

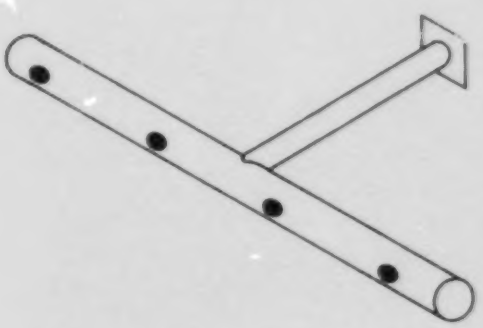
Wooden Drop Structure

4. DELIVERY FOR FURROW IRRIGATION

Spiles or turnouts are boxes or tube-like structures in the bank of a head ditch one to four inches in diameter that provide and control the flow of water from the head ditch into corrugations or furrows. They are used at places where the head ditch is nearly flat. They usually have some type of a simple slide gate to regulate the flow. They must be long enough to extend through the ditch bank and should be equipped with an anti-seep collar and a slide gate.

The water elevation in this ditch section can then be controlled by a check. The water should be maintained high enough over the spile openings to produce a full flow when desired.

Spiles made in the shape of a T have also been used successfully. The stem of the T is buried in the bank with the open end free to take water. The cross arm lays across several furrows and discharges water into these furrows from holes in the pipe. The flow is regulated by a slide gate in the intake end of the stem. Figure 10 illustrates this type of spile.



T-SPILE

FIGURE 10

Spiles need not be expensive, but economical and proper use of water should be kept in mind. The simplest and most convenient device is desirable as long as it is substantial. A watertight gate or plug should be provided for the inlet. Clay pipe tiles, metal pipes, iron pipe or casing, or concrete pipe are all usable.

In developing countries, cost of spiles or turnout pipes are often prohibitive. Short lengths of bamboo have been found to serve the purpose very well. While bamboo has a hollow internode, the node of the plant is solid. This must be punched or drilled out before it can be used.

Siphons

Siphons are used to deliver water from a supply ditch, over the bank and onto the land. They permit easy control of water and eliminate cutting of ditch banks. They are particularly adaptable to the furrow method of irrigation. Good, well-shaped ditches with sufficient ditch height are essential.

Siphon tubes are made commercially and are available in metal, plastic and rubber. Sizes used for row irrigation vary from 3/4 inch to two inches in diameter. Small tubes are recommended for heavy soils and steep slopes.

Water flows through the tube by the force of atmospheric pressure on the water in the ditch. One end of the tube is placed in the ditch. The other end is placed outside the ditch at or near the ground surface and must be lower than the water level in the ditch. The tube must be completely full of water for flow to start.

How to Set a Siphon

1. Insert siphon in irrigation ditch and fill it completely with water.

    a. Be sure "field end" or long end is pointing toward field.

    b. Keep "ditch end" or short end of siphon immersed. ("Pumping action" may be used to fill siphon.)

    c. When siphon is full, put hand tightly over "field end" of siphon.

2. Lift "field end" of filled siphon from ditch.

    a. Do it quickly.

    b. Hold hand firmly over "field end".

c. Be sure "ditch end" of siphon is below water surface.

d. Only lift siphon high enough to clear ditch bank.

3. Quickly move filled siphon toward field.

a. Keep hand tightly over "field end" of siphon.

b. Be sure "ditch end" of siphon stays in water at all times.

4. Lower filled siphon over ditch bank and remove hand from "field end".

a. Be sure siphon is lowered before removing hand.

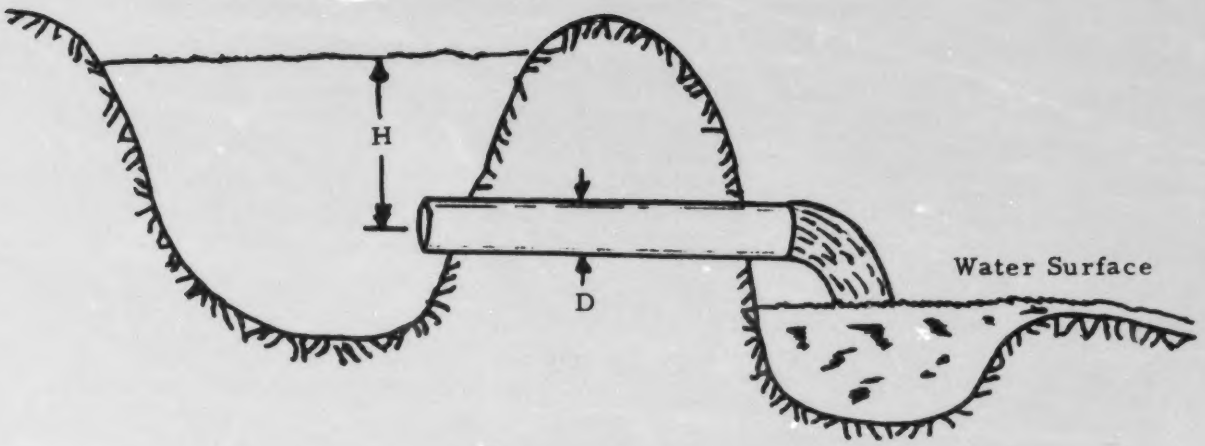
b. "Field end" of siphon must be lower than the water level of the ditch.

c. Keep "ditch end" of siphon in water at all times.

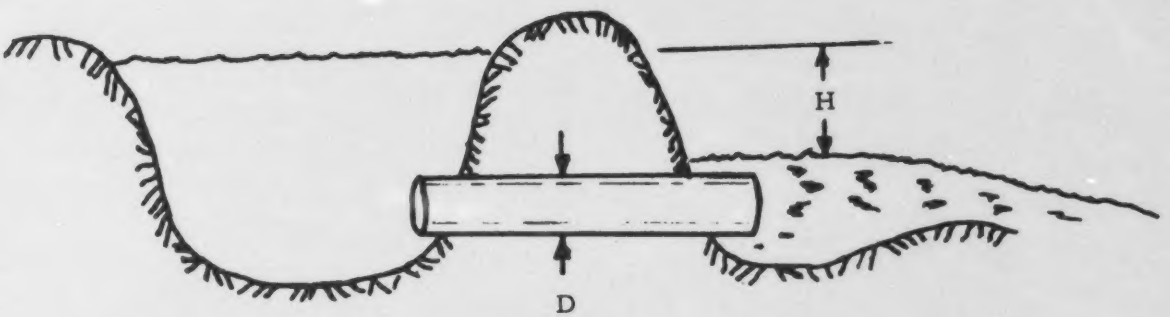
5. Set siphon firmly on bank.

a. Brace with soil if necessary to prevent sliding.

b. "Ditch end" should be several inches below water surface to allow for slight lowering of water level in ditch.



FREE FLOW - Outlet is not submerged



SUBMERGED FLOW - Outlet is submerged

FIGURE 11

Two methods of installing spiles or pipe outlets in head or feeder ditches.

One of the difficulties which is apt to happen is air getting into the tube from the discharge end after the water starts or during the priming process. When this happens, flow is restricted. With plastic tubes, you can see the air bubble at the top of the curve, but in metal, black plastic, or rubber tubes, this is not possible. If it looks as if the flow should be greater, it is best to reprime the tube.

The rate of flow through a siphon depends on its diameter and the pressure head. The head is the vertical distance from the water surface in the supply ditch to the water surface on the outlet side, as shown in Figure 12 below.

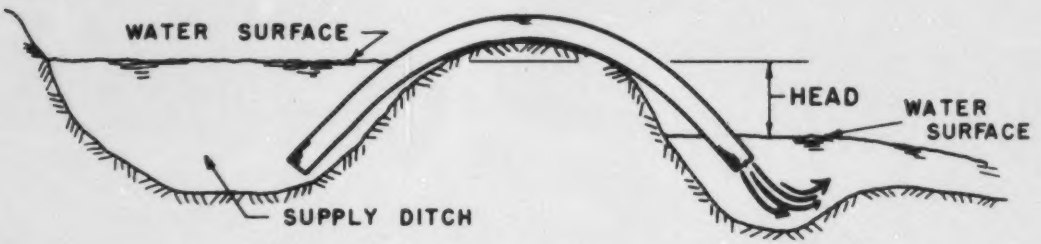
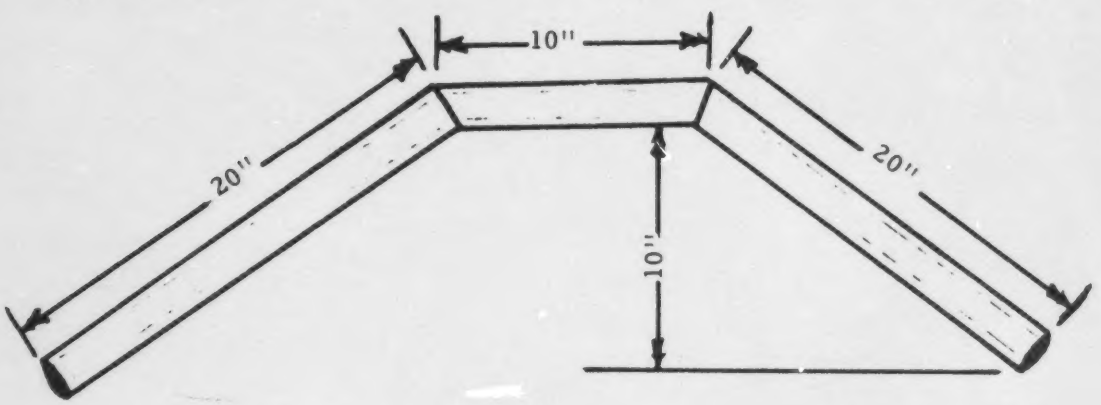


FIGURE 12

Measurement of head to determine rate of flow through a siphon tube.



Solder all joints
and seams air tight.

3/4" to 3" Diameter

(Village Technology Handbook No. 2. USAID)

FIGURE 13

Siphon Tube Construction Details

Commercially made siphon tubes will probably be too expensive for the peasant famer in developing countries. Figure 13 shows the dimensions of a siphon tube which can be made by a local artisan. Care should be taken that the seams are well soldered so no air leakage occurs.

TABLE 16

RATE OF DISCHARGE IN GALLONS PER MINUTE
FROM SIPHON TUBES OF VARIOUS SIZES

Head In Inches	Size of Siphon Tube				
	1"	1-1/4"	1-1/2"	1-3/4"	2"
2"	5	8-1/4	13	17	21
4"	7	12	19	25-1/2	32
6"	9	15-1/2	24	32	41
9"	11	19	29	39	50

UNIT D - DRAINAGE

Drainage is the removal of excess water from the land to prevent salt accumulation, allow earlier planting of crops, increase the root zone, aerate the soil, favor growth of soil bacteria, and for reclamation of arable low lying or swamp areas. Practically every valley where irrigation has been carried on for any considerable length of time has lands in need of drainage. Several classes of land in irrigated sections require artificial drainage in order to be fitted for crop production. Man-made swamps, the product of irrigation, constitute the greatest area in need of drainage.

All plans that are developed for introducing water to land, either as a supplemental supply or for new irrigation, should provide for removal of excess water from the land.

Drainage problems are usually made apparent by:

1. Standing water or salt deposits on the surface of the ground.
2. Scalding of crops by summer water ponding.
3. Propogation of mosquitoes in irrigated fields.
4. Soil compaction and resultant poor water penetration.
5. Difficulty in carrying on farm operations because of poor tractor footing.
6. Accumulation of salts in the soil.
7. Poor root growth due to a high water table.
8. Plant root diseases.
9. Development of uneconomical plant communities.

In general, there are two main types of drainage situations; surface and subsurface.

Surface Drainage

Surface drainage is affected by topography and vegetation. Excess irrigation water must be removed to alleviate ponding and water logging of the lower parts of the field. Storm water must find its way into a drainage

channel in such a manner that erosion is controlled, but soil aeration is not inhibited. On some drainage projects, open drains are used to convey water to distant outlets. Because of the high cost of construction and maintenance, the inconvenience in movement of machinery, and the value of land removed from production, open ditch drainage is expensive and often inconvenient, but it does have a place in many systems. The open ditch, as its name implies, is merely a waterway cut into the soil so that it will receive drainage from adjacent lands.

Excess rainfall can be controlled and disposed of by terraces and diversions leading to grassed waterways. On flat land where there is no erosion hazard, shallow surface drains are used.

Tail ditches generally are shallow open drains large enough to carry away irrigation waste water and storm water runoff. Storm runoff generally governs capacity. The grade of these ditches should be governed by the soil's resistance to erosion. Banks of these ditches must be protected from erosion by surface water inlet structures or by establishing vegetation on flattened slopes.

A combination of field ditches and land leveling would be most practical. It would take an unreasonable amount of field ditches to do a good job of moving water from most fields without land leveling. Deep channels to carry the final collection into an accepted area are often constructed on field boundaries.

Subsurface Drainage

Subsurface drainage requires a thorough study of subsurface conditions. Test pits, borings, and permeability tests permit evaluation of the internal drainage capacity of the soil. Borings are commonly used to determine depth and fluctuations of the water table, depth of and thickness of the substrata, and to ascertain the character of the substrata.

The first step in solving a drainage problem is to determine the source, direction of movement and amount of excess water. An important factor is the permeability or hydraulic conductivity of the soil--which means the rate of movement of water through the soil. Excess groundwater must be removed by either deep open ditches or tile to provide an effective root zone depth. Tile drains have been found much more practical than deep open ditches.

The two general methods for removing excess water are by interceptor drains or relief drains. The appropriate method to use depends

primarily on the flow characteristics of the water, the topographic features of the area, along with the subsoil conditions.

It is always a good idea to intercept the excess water before it reaches the point where damage occurs. For this reason, an interceptor drain should be placed to intercept and remove water before it reaches the point of damage. In this case, the tile should be placed as deep as possible in order to intercept the maximum amount of water flowing downslope.

Relief drainage systems are installed in either a systematic or random pattern within an affected area. These laterals drain water to a main line which in turn discharges it into a trunk drain. Lateral tile lines are placed parallel to the direction of groundwater movement and often are arranged in a gridiron or herringbone pattern.

Soil Salinity

When salinity in soils becomes too great for efficient crop production, it must be removed or the land must be abandoned. Saline soils are soils having excess soluble salts that make the soil solution sufficiently concentrated to injure the plants and impair soil productivity. One of the first effects of soil salinity is the inability of the plant to absorb enough water due to an increase in the osmotic pressure in the soil solution.

Arid region soils contain relatively large amounts of soluble salts. In the more humid regions, these salts have been leached out by rainfall. The small rains of the arid regions do not penetrate far enough into the soil to cause percolation of these salts. Lack of percolation, along with excessive evaporation, causes an accumulation of soluble salts on the soil surface that are injurious to plant life. The basic cause of salinity problems is usually inadequate application of water and/or poor drainage, or the application of water having a high concentration of soluble salts.

A high concentration of salts in the soil may result from a high water table. During periods between irrigations, a high water table favors the upward capillary flow of water to the land surface where the water evaporates. The soluble salts carried by the upward moving water cannot be evaporated; hence, they are deposited on or near the soil surface.

The most effective method for the removal of salt from soil is by means of water which passes through the root zone of the soil. To prevent salt accumulations, and consequent decrease in crop yields,

irrigators must remove as much salt as is brought in. In some areas, a limited supply of irrigation water is spread over too many acres, with the result that the soil is not wetted below a few feet. In other areas, the groundwater table is so shallow as to prevent the leaching of salts from the root zone. Upward flow of water from these shallow water tables results in a continuing accumulation of salts in the surface soil. If it were possible to maintain a moisture distribution in irrigated soils so that the water flow would be continuously downward, there would be relatively little trouble from salinity.

Adequate drainage is of extreme importance for either reclamation of saline lands or the maintenance of lands free from salinity. It is usually essential that water volumes in excess of crop requirements be applied to saline and alkali lands and be made to percolate through the soil to leach out excess salts. Salts dissolve in the water passing through the soil. In all cases, water must pass beyond the root zone to remove excess salts from the root zone. Therefore, leaching is impossible without natural or artificial drainage.

Application of water to assure that all the surface is covered, even if ridges and knolls must be leveled first, should be performed. If the subsoil is impervious, subsoiling must be done. Waste water should not be allowed to run off but should percolate down through the soil. For this reason, a series of dikes and checks should be built so adequate ponding can be accomplished, each check having as large an area as slope and water supply will permit. It should be kept in mind that excessive leaching will also remove soil nutrients from the soil, especially nitrates. Overuse of irrigation water also adds to the drainage problems.

Permanent reclamation of saline and alkali lands require several essential steps;

1. lowering of the water table,
2. satisfactory water infiltration,
3. leaching of excess salts out of the soil,
4. intelligent future management of the soil.

Some alkali and saline soils are low in available phosphorous and will give better crop yields if phosphate fertilizers are used. Liberally applying barnyard manure, plowing under cover crops, avoiding of plowing or of other farm operations when the soil is too wet or too dry are all helpful. Keeping drains open and in good repair and applying only enough water to assure adequate penetration into heavy soils, preventing excessive evaporation, are essential steps in maintaining permanent relief from waterlogging and a continuation of soil productivity.

Surface Runoff

For the protection of roads, irrigation systems, buildings and fields, the maximum rate of runoff should be determined and allowed for in all drainage systems. Most drainage structures can be flooded for a short period of time, but peak rainfall intensities and runoff data should be determined so that the system (bridges, culverts, etc.) can be adequately designed to handle the runoff. It may be more economical to design these structures on a 10 - 25 year recurrence expectancy. This means it would be planned so it would only be exceeded once in every 10 - 25 years.

In calculating runoff on small watersheds, this formula has wide usage:

$$Q = CIA$$

Q = Flood peak or cubic feet per second
C = Runoff coefficient
I = Rainfall intensity, inches per hour
A = Drainage area in acres

For a drainage area in a diversified farming area, the value of C is often used as 0.50. Some of the figures for C under varying conditions are as follows:

	0-5% Slope	10-30% Slope
Cultivated land	0.60	0.72
Pasture land	0.36	0.42
Timber land	0.18	0.21

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UNIT E - IRRIGATION PLANNING AND SPECIAL INFORMATION RELATED TO IRRIGATED CROP PRODUCTION AND RELEVANT PROBLEMS

1. USING TOPOGRAPHIC MAPS FOR IRRIGATION PLANNING

An accurate topographic map of the area under consideration is a necessity for good irrigation planning. The size and shape of irrigated fields, direction of irrigation runs, location of turnouts and farm ditches, irrigation methods, size of irrigation streams, and location of waste disposal systems all depend upon soil, topography, and drainage systems.

Several very important criteria should be considered in developing an irrigation layout:

1. Obtain reasonably uniform application of water of the required amounts.

2. Soil erosion should be kept to a minimum.

3. Runoff should be minimized.

4. A minimum amount of land should be used for ditches and control structures.

5. Irrigation systems should fit on field boundaries if possible.

Delivery channels, of course, should be located at such an elevation that the water may be gravity fed to the fields. The layout should provide for sufficient water within each field. Head ditches should be located to avoid major slope or irrigation grade changes. These ditches should be constructed with enough grade for water to flow, but not enough for erosion to take place.

The general "lay" of the land will dictate the location of feeder ditches. It is sometimes necessary to lay out borders and irrigation runs diagonally across a field. This makes irrigation somewhat more difficult because of varying length of run. General overall slope of the land will dictate this.

Drainage channels for removal of waste water can also be located from a topographic map. By visual observation of the average slope, the most desirable direction of irrigation may be determined.

Although a soil map showing type and depth of soil is needed in conjunction with a topographic map, the amount of necessary earth moving to provide for an even grade may be determined. As this is very expensive, the field should be studied carefully before work is started. It should be determined that the soil is deep enough before attempting to level the land. Even sprinklers apply water more uniformly to a smooth land surface.

If the plan has been done well, the irrigation system will deliver the amount of water needed to each field, will allow easy control of the irrigation stream and apply irrigation water with the least amount of labor, will permit an efficient use of the water, insure adequate drainage and conserve the soil while increasing its fertility.

2. PUMPS

In many instances, large areas of land are so situated that available water cannot be brought to them by gravity. In many of these areas, water is raised by some mechanical device from its natural source so it will then flow by gravity over the surface of the land. Pumping is necessary for sprinkler irrigation. Pumping is oftentimes extremely important for drainage.

The power units commonly used in irrigation are foot-pounds per second and horsepower. One horsepower is equivalent to 550 foot-pounds per second. One horsepower would lift 1 CFS a vertical distance of 8.8 feet at 100 percent efficiency. It would require 125 foot-pounds per second to lift 2 cubic feet per second of water a vertical distance of 1 foot. These figures are all theoretical because it is impossible to get 100 percent efficiency in a pumping unit. Average efficiencies of 70 - 80 percent for centrifugal pumps and 70 - 75 percent for deep well turbine pumps are commonly found.

The depth of wells varies widely. In some instances water is only lifted a few feet, while in others, it is raised several hundred. Cost of raising the water should be carefully considered in deep wells. Use of shallow wells should not be overlooked for irrigation purposes.

Pumps used for irrigation purposes are of many different makes. In general, they can be characterized on the size of discharge in relation to the amount of head.

In deep wells, water is generally lifted with a turbine pump. Installations of as much as 1,000 feet below ground surface have been successful. They are generally driven by an electric motor. An impeller blade or series of blades positioned on a vertical shaft in a bowl or bell housing is placed below the water. Being submerged, these pumps require no priming. High efficiency is dependent upon a close fit of the impeller blades against the pump housing. Because the operating parts are inaccessible and difficult to inspect, low efficiency is common in this type of pump after a period of hard use.

Centrifugal pumps are only used where the water must be lifted less than 15 - 20 feet. Their use is governed by elevation and susceptibility of losing prime.

Centrifugal pumps are built on both vertical and horizontal shafts. They have the advantages of being efficient, simply constructed, relatively

free of trouble, low cost, easy to install, and capable of high speeds. Their chief disadvantage is the necessity to prime the pump, or to fill the suction pipe and pump case with water and thus expel all air. A good foot valve is essential to hold the water in the intake line while it is filled. A good foot valve will also hold water in the line so that priming will not be necessary each time the motor is started.

When only small volumes of water are required, a very economical method to use would be a windmill. Operating strictly on wind velocity, windmills are capable of generating in excess of 1 horsepower in a 20 mph wind. They are capable of lifting water, by using a foot valve and reciprocating lift rod, up to 180 feet. They are very useful in areas where wind currents are dependable and of sufficient velocity to turn the fan which generates the horsepower.

There are several other types of pumps that can be used to lift water short distances from streams, shallow wells, or storage reservoirs. Among these are the windlass, the endless chain and bucket, or the common foot valve and lift pump. A rather unique device that is capable of lifting small amounts of water up to 60 feet is the continuous rope unit. Utilizing any source of power, it can be made from very cheap materials in a very small amount of time.

Animal power is often used in a series of bucket lifts to raise water from a stream bed for irrigation purposes.

3. PIPELINES

A method of conveying water from its source to the fields is to replace all or part of the open earth ditch with underground concrete pipeline. The investment per acre is much higher than for open ditches, but the advantages are many. For example, labor is reduced and water losses from seepage and ditch evaporation are practically eliminated. Since pipelines are costly, careful planning is required for each location, capacity requirements, and good construction requirements.

Pipe conduits can be used in most places but are particularly suited to areas where seepage losses are high. Pipe can be used in areas that are difficult to excavate and to carry water down steep slopes. Less tillable land is taken up and maintenance work in general is less than for open ditches.

Two general kinds of pipeline are used--low pressure and high pressure. Low pressure lines are open to the atmosphere and are used with operating heads of less than 20 pounds per square inch. High pressure lines are used where operating heads of more than 20 pounds per square inch are required.

Low pressure pipelines are used primarily with surface irrigation methods. It is important that a pipeline be large enough to convey the flow needed in different fields under present and future conditions. If economically feasible, it should be large enough to supply the water required during the period of peak crop use even though this full capacity may be needed in only a small part of the total irrigating season.

High pressure pipelines generally are used to convey water for sprinkler irrigation. Since sprinklers usually require 40 pounds per square inch or more of pressure for efficient water distribution, the pipeline must be designed to withstand this pressure.

Specialized structures are needed on pipelines to control water and to protect them against damage. Gravity inlets are often used to get the water into the pipeline. This structure should include a sand trap and trash screen so that full pipe flow is developed and trash is kept out. If water enters the pipeline from a pump, a stand should be used. A pump stand is a vertical pipe extending above ground from the pipeline to permit overflow from excessive pressure, and to allow release of air involved in the pumped stream.

Vents to relieve pressure and release air are used at all high points of a pipeline, at points where its slope sharply increases in the direction of flow, or below any structure that entrains air. By allowing air to escape, vents permit a pipeline to carry more water, relieve surges, and prevent damage to the line when gates or valves are opened or closed.

The usual flow control structures are needed in a concrete pipeline to regulate the flow into branching lines, and to relieve pressure, as well as furnishing an outlet for the water where required.

Outlets in concrete lines usually consist of risers built from vertical sections of pipe, which are saddled onto the pipeline and attached to it with a waterproof joint. Some kind of a valve or gate is installed in the riser to regulate discharge through the hydrant.

Alfalfa valves are used to distribute water directly to border strips, basins, or ditches. An alfalfa valve consists of a handle and cap plate attached to the threaded rod that moves up or down as the handle is turned. When the valve is closed, the cap plate fits the edge of the valve case and makes it water tight. When the plate is lifted by turning the handle, water is released from all sides of the valve.

Orchard valves are quite similar to alfalfa valves but are used if a smaller flow is acceptable. It is also possible to place an additional hydrant over this type valve to deliver water into surface pipes or ditches.

Capped risers are often found in these types of water systems. In this type, the top of the riser is capped, slide gates are installed on the outside of the riser, and flow is controlled by adjusting line pressure and slide gate openings. This type of outlet is used only in irrigating orchards and permanent crops where small flows are distributed to the individual furrows. Capped pot outlets should not be used where the pressure will be more than one to two feet above ground surface.

Lined Ditches

Open ditches are the most common method of carrying irrigation water, but many are not efficient. In porous soils, unlined ditches lose considerable quantities of water by seepage. Soil permeability probably is the most important factor. Losses are greater if the water is carried a long distance. Vegetation along a ditch contributes to water loss through transpiration. Seepage may also damage adjoining lands by raising the water table. Grade control structures are required in ditches if the flow develops an erosive velocity.

Ditch linings can be effectively used to control seepage and bottom and bank erosion. For any given flow, lined ditches can be smaller than unlined. Lining protects land against waterlogging, prevents some damage by rodents and reduces cost of maintenance, cuts down on interruption of delivery, and helps in the control of weeds.

Selecting a lining material should be governed by the availability of the material and equipment needed to install it, ditch size, climatic conditions, etc. Many kinds of material are used which include concrete, rock masonry, brick, natural clays of low permeability, and different asphalt, rubber, or plastic compounds.

Many ditches have been lined for a very low cost by using earth materials. If the materials are available, three methods are employed:

1. Placing a blanket of relatively impervious material over or within the canal bed.

2. Dispersing clay in the water and having it filter out as the water seeps through the bed.

3. Chemically stabilizing the earth material to make it less permeable.

One of these chemical stabilizers is called bentonite. It is a low cost material similar in appearance to ordinary ground clay. It swells 12 to 15 times its dry size when wet and fills the voids through which water seeps.

For smaller irrigation canals and laterals, precast concrete or cut stone slabs are used. Masonry rock and brick work also make good linings. Concrete alone has a high initial cost but several advantages. It is durable, maintenance costs are at a minimum, and capacity is increased because of its relatively smooth surface. Thickness of the concrete generally runs from 1-1/2 to 3 inches.

4. TYPICAL PROBLEMS INVOLVING WATER MEASUREMENT AND DELIVERY TO SUPPLY PROPER AMOUNTS OF WATER TO SOILS

As an irrigator, you need to know four quantities. One is the depth of water you wish to apply, the second is the size of irrigating stream in cubic feet per second or gallons per minute, the third is the time the water will run, and the fourth is the number of acres in the field.

If you know three of these quantities, you can always figure the fourth from this handy formula:

One cubic foot per second (CFS) for one hour equals one inch depth on one acre.

Example (1) To find how long you would need to run a stream of 3 CFS to apply 5 inches gross depth of water to a 15 acre field,

1 CFS for 1 hour	=	1 acre inch
3 CFS for 1 hour	=	3 acre inches
	and	
5 inches x 15	=	75 acre inches needed.
Therefore, $\frac{75}{3}$	or	25 hours

Example (2) To figure how many inches have been applied when a stream of 4 CFS has run for 10 hours on an 8 acre field:

1 CFS for 1 hour	=	1 acre inch
1 CFS for 10 hours	=	10 acre inches
4 CFS for 10 hours	=	40 acre inches
$\frac{40 \text{ acre inches}}{8 \text{ acres}}$	=	5 inches applied

5. MOISTURE REQUIREMENTS OF VARIOUS CROPS

During and immediately following irrigation, water will soak through the soil profile until the wetted depth all reaches field capacity. If an efficient irrigation is made, the wetted area is confined to the root zone. The water available for plant use is restricted to that area through which plant roots can penetrate.

The feeder root depth of plants will vary from one foot to approximately four feet. While some plants have deep tap roots, they supply only about 15 percent of the total water plants use. The remaining 85 percent is supplied by the feeder roots. Therefore, when the soil moisture drops below the wilting point in the feeder root zone, all growth will stop. This, of course, causes a distinct stress on the plant.

It is a proven fact that plants take water at a uniform rate when the soil moisture is at any stage between field capacity and just above the wilting point. If the applied water is evenly distributed over the entire growing area, and soil moisture kept somewhere between these two points, a constant and uniform growth will be promoted.

To insure a minimum water use and a maximum production and quality of product, it is necessary to know the soil, the plant feeder root zone, the plant water use and climatic conditions, and apply water accordingly.

TABLE 17

PEAK MOISTURE USE FOR COMMON IRRIGATED CROPS

Crop	Acre Inches Per Day			
	Cool	Moderate	Hot	Desert
Alfalfa	.20	.25	.30	.35
Cotton	.20	.25	.30	.35
Pasture	.20	.25	.30	.35
Grain	.15	.20	.22	.30
Potatoes	.14	.20	.25	.30
Beets	.20	.25	.30	.35
Orchards	.20	.25	.30	.35
Orchards/cover	.25	.28	.35	.38

TABLE 18

FEEDING DEPTH OF MAJORITY OF PLANT FEEDER ROOTS

Crop	Feeder Root Depth
Alfalfa	3 - 3.5 ft.
Beans	2
Beets	2 - 3 ft.
Cabbage	1.5 - 2
Carrots	1.5 - 2
Corn	2.5
Cotton	4
Grain	2 - 2.5
Grain Sorghum	2.5
Grapes	3 - 4 ft.
Lettuce	1 ft.
Nuts	3 - 4 ft.
Onions	1.5
Orchard	3 - 3.5
Pasture	1.5 - 2
Peanuts	1.5
Peas	2.5 ft.
Potatoes	2 ft.
Soybeans	2 ft.
Sweet Potatoes	3 ft.
Tobacco	2.5 ft.
Tomatoes	3 ft.

APPENDIX

EXPLANATION FOR IRRIGATION IMPLEMENTS

Efficient irrigation requires uniform applications of adequate amounts of water at proper times. Careful preparation of land for irrigation methods result in a savings of labor, water and soil, and in increased yields. Land preparation for irrigation often includes grading and smoothing of the soil surface, preparation of levees and ridges, and water conveyance and drainage ditches.

A few simply constructed bullock drawn implements greatly facilitate land preparation. Plans for such implements, which can be built by a village carpenter or blacksmith having ordinary skills, are included in this section.

Buck Scraper

The wooden buck scraper is possibly the most useful low-cost animal drawn implement for leveling land for irrigation. The model shown can be made from locally available materials. It has been extensively tested and is a proven, successful design.

Although the buck scraper is a simple implement, certain exact procedures must be followed to make it work effectively. The proper operation involves the following steps:

1. To bring the scraper to loading position, the operator must approach the tailboard from the side opposite the pipe handle. Care must be taken that the operator is clear of the handle as it will snap back as soon as the bullocks move forward.

2. To load the scraper, the operator must move forward, place one foot on top of the scraper board and keep the other foot on the tailboard as far forward as possible. The weight of the operator should be applied directly over the cutting edge while the scraper is being loaded. Since the scraper will usually carry a full load without the operator riding or holding the handle, he can step off to lighten the draft.

3. To unload, the handle is lifted and the load is dumped. Spreading may be done by slowly raising the handle which allows the load to be distributed in a thin layer.

The buck scraper of the size given in the drawing, can be pulled by a pair of average size bullocks. For small oxen, a skillful operator can adjust the load to suit their strength, or the size of the scraper may be reduced to 5 feet.

Wooden Float

In order to finish the leveling job, the surface must be smoothed. This job may be done with a float, a long sled-like drag which operates on the same principle as a carpenter's plane. As the float is pulled forward, the cutting edges remove the high spots and push this soil into the low areas ahead. For best smoothing on flat, level fields, it is desirable to float the surface three or more times by going across the field lengthwise, crosswise, and diagonally.

The float may be constructed in various sizes to meet the power available. A width of 3 to 6 feet is satisfactory for animal power. It must be emphasized that an overall length of about 16 feet or more is necessary if the float is to do a precision job of land smoothing.

A-Frame Ridger

A homemade A-Frame Ridger is a suitable implement for making ridges or bunds. It will gather soil from a wide strip and leave very little furrows beside the ridge. The operator usually rides on the ridger, thus applying his weight to get a more effective job. The operator has a choice of standing positions on the cross planks on top of the ridger. The largest ridge and the one requiring the most power is formed when the operator stands on the cross plank nearest to the bullocks. As with other animal drawn implements, the height and length of hitch greatly influences the draft and the performance of the A-Frame Ridger.

V-Ditcher

The V-Ditcher is a useful tool for construction or cleaning of field channels for irrigation or drainage. It is also sometimes used to make border ridges or bunds.

The V-Ditcher's operation in constructing a ditch is much like that of an oversized mold board plow. The channel line is first laid out with surveying instruments. A mold board plow is used to make a furrow where the line has been staked. The V-Ditcher is pulled back and forth in this ditch until a symmetrical ditch of almost any size and proportions can be made.

One pair of bullocks or more may be used to pull the V-Ditcher. It is important, however, that the animals walk on the outside of the channel. Changing the operator's position of the V-Ditcher lowers or increases the depth of cut and also increases the animal power required to pull it. The width of the ditch may be increased or decreased by lowering or raising the handle of the ditcher.

BUCK SCRAPER

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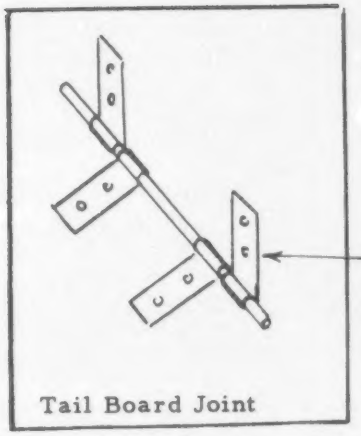
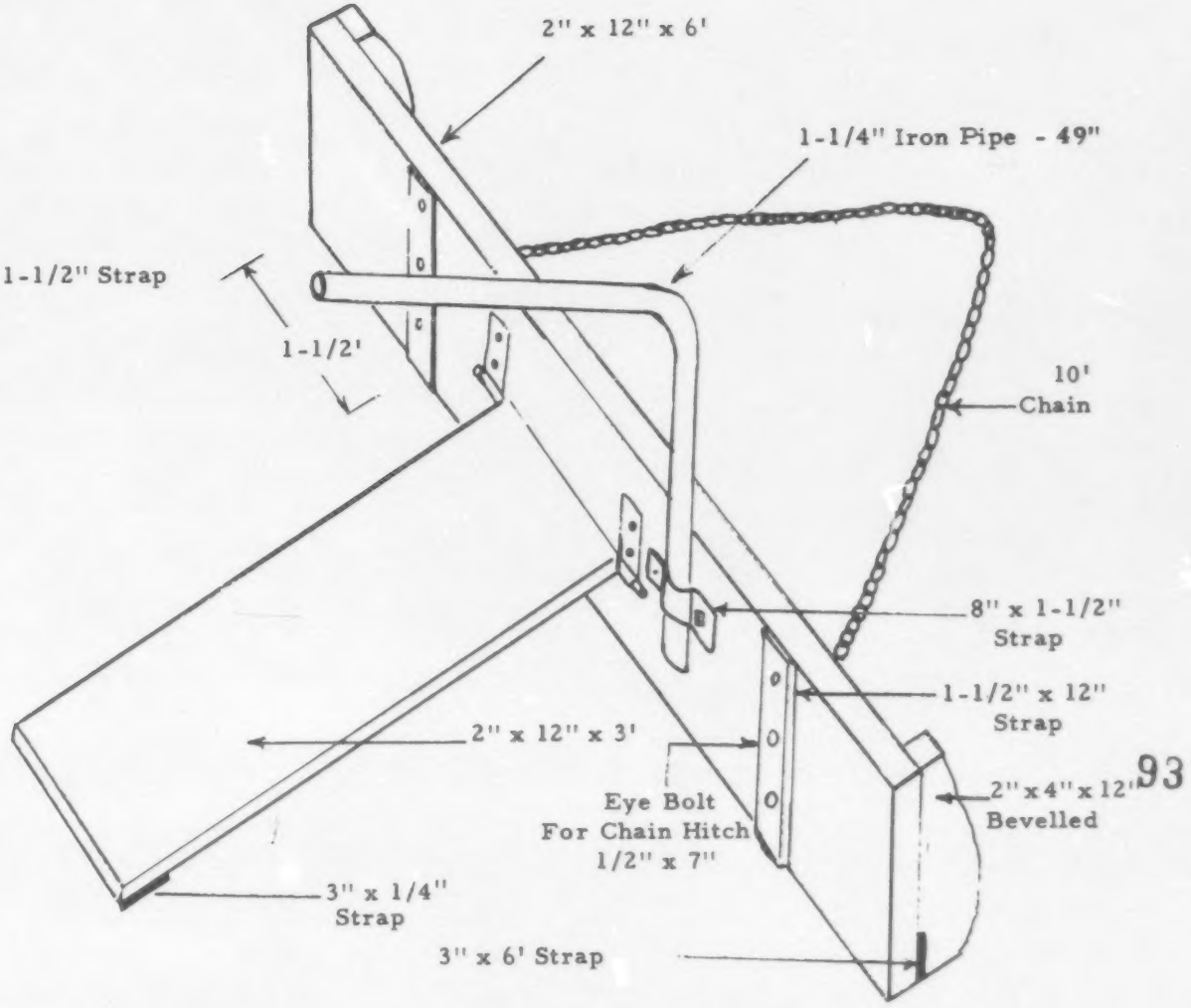
Ext. Bul. No. 1





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MATERIALS FOR BUCK SCRAPER

NUMBER OF PIECES	DIMENSIONS	ITEM
1	2" x 12" x 6'	Buck Board
1	2" x 12" x 3'	Tail Board
2	2" x 4" x 12"	Wooden Blocks for ends
1	$1\frac{1}{4}$" x 49"	Iron Pipe Handle
1	$\frac{1}{4}$" x 3" x 6'	Steel Cutting Edge
4	$\frac{1}{4}$" x $1\frac{1}{2}$" x 6"	Strap Iron for Hinges
2	$\frac{1}{4}$" x $1\frac{1}{2}$" x 12"	Strap Iron for Reinforcement
1	$\frac{1}{4}$" x $1\frac{1}{2}$" x 8"	Bent Strap Iron Pipe Clamp for Handle
1	$\frac{1}{2}$" x 16"	Rod for Hinge Pin
2	$\frac{1}{2}$" x 7"	Eye Bolts for Pull Chains
1	$\frac{1}{2}$" x 4"	Carriage Bolt for Handle
2	$\frac{1}{2}$" x 3"	Carriage Bolt for Handle Clamp
20	$\frac{1}{2}$" x 3"	Carriage Bolt for Blade, Strap, etc.
4	$\frac{1}{2}$" x 6"	Carriage Bolt for Ends
1	$\frac{1}{4}$' x 12" x 3"	Steel Plate for Tail Board
1	1" x 10'	Pull Chain

WOODEN FLOAT

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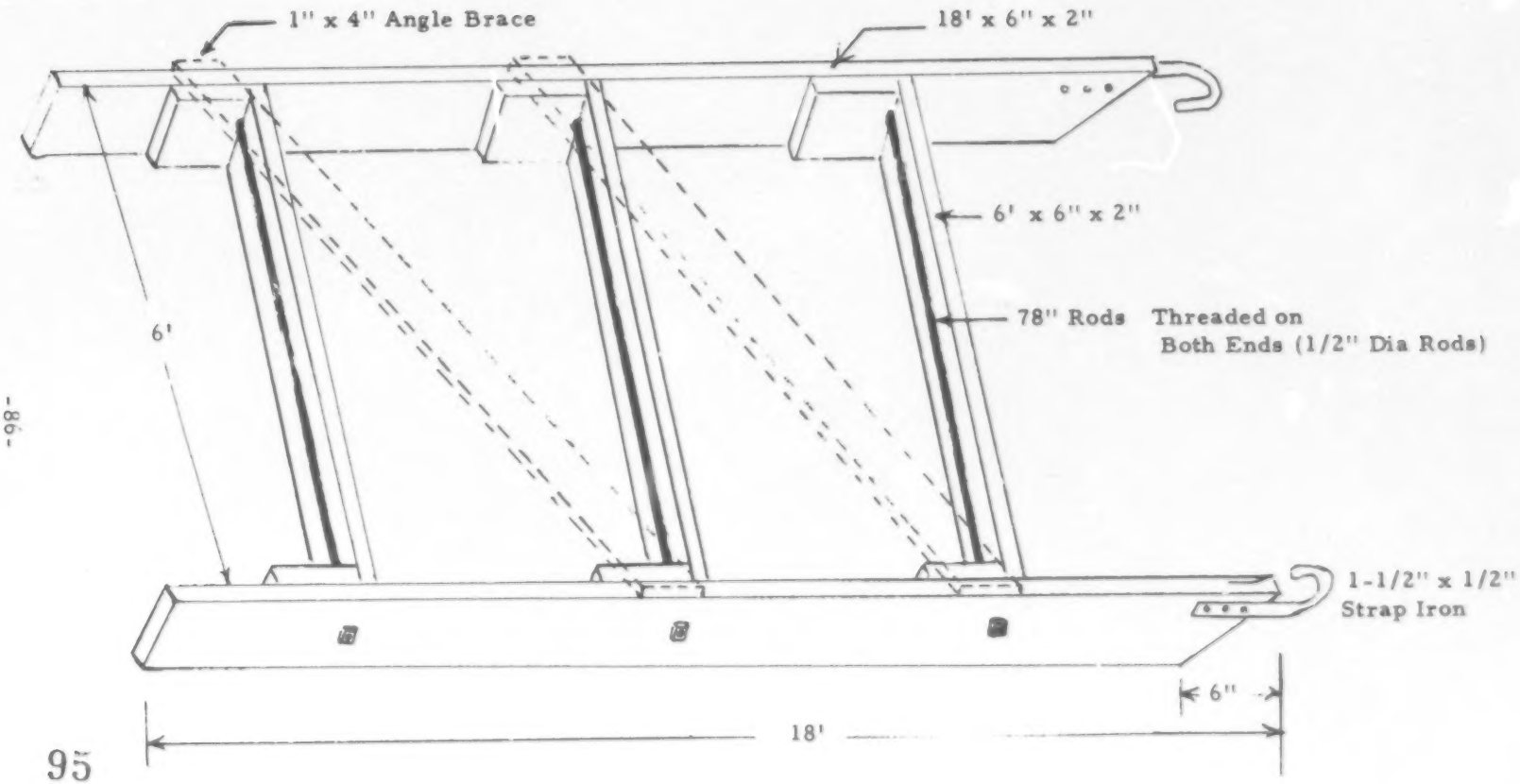

MATERIALS FOR FLOAT

NUMBER OF PIECES	DIMENSIONS	ITEM
2	2" x 6" x 18'	Runners
1	2" x 6" x 6'	Rear Blade
1	2" x 6" x 6'	Middle Blade
1	2" x 6" x 6'	Front Blade
6	2" x 6" x 6"	Side Blocks
3	$\frac{1}{2}$" x 6'6"	Steel Rod (threaded 2" on both ends)
6	$\frac{1}{2}$"	Nuts and Washers
2	$\frac{1}{2}$" x $1\frac{1}{4}$" x 18"	Steel for hitch
2	1" x 4" x 10'	Cross Bracing
4	$\frac{1}{2}$" x 3"	Carriage Bolts and Nuts
36	3"	Nails
48	$1\frac{1}{2}$" #12	Screws

A - FRAME RIDGER

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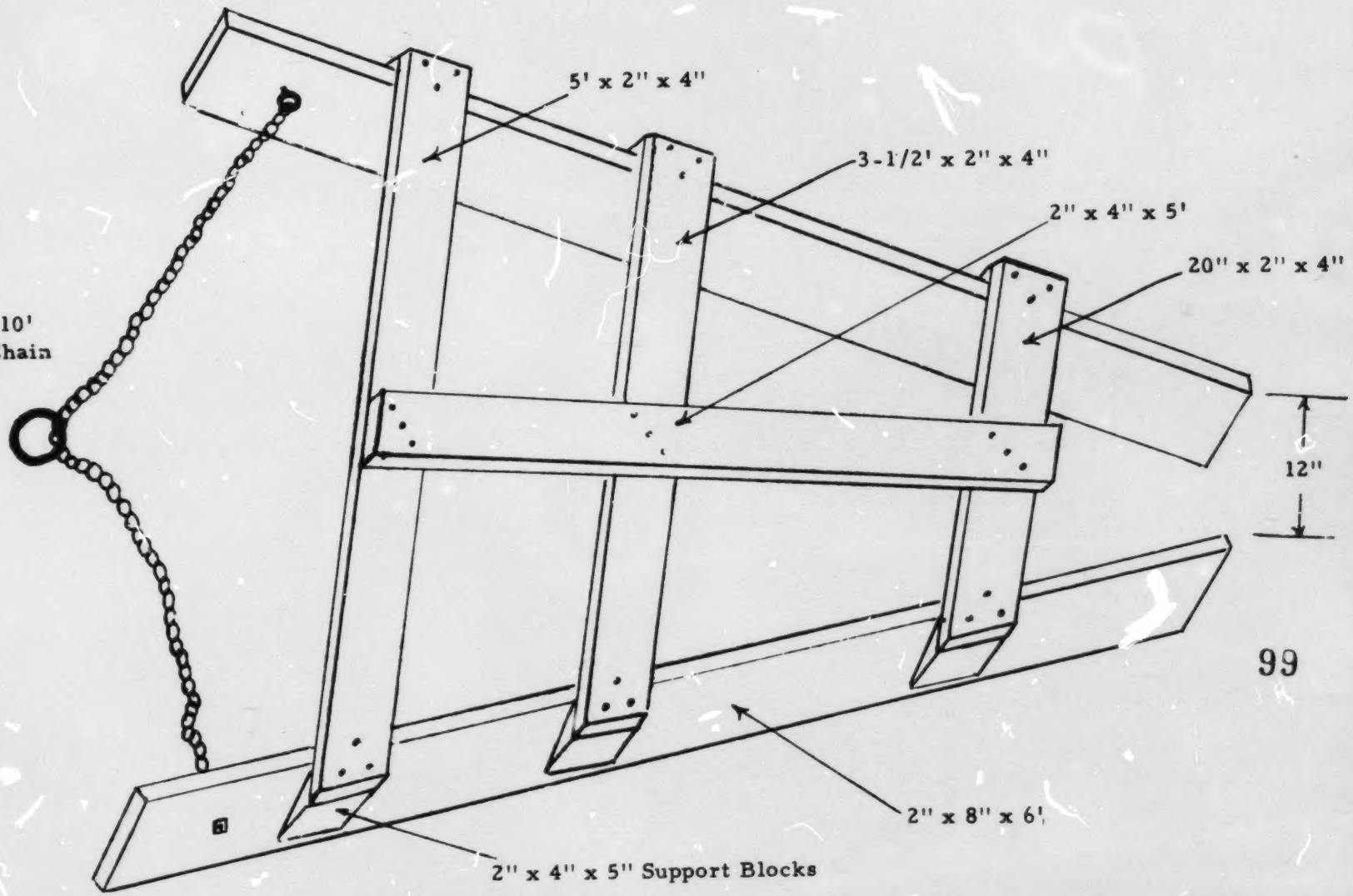

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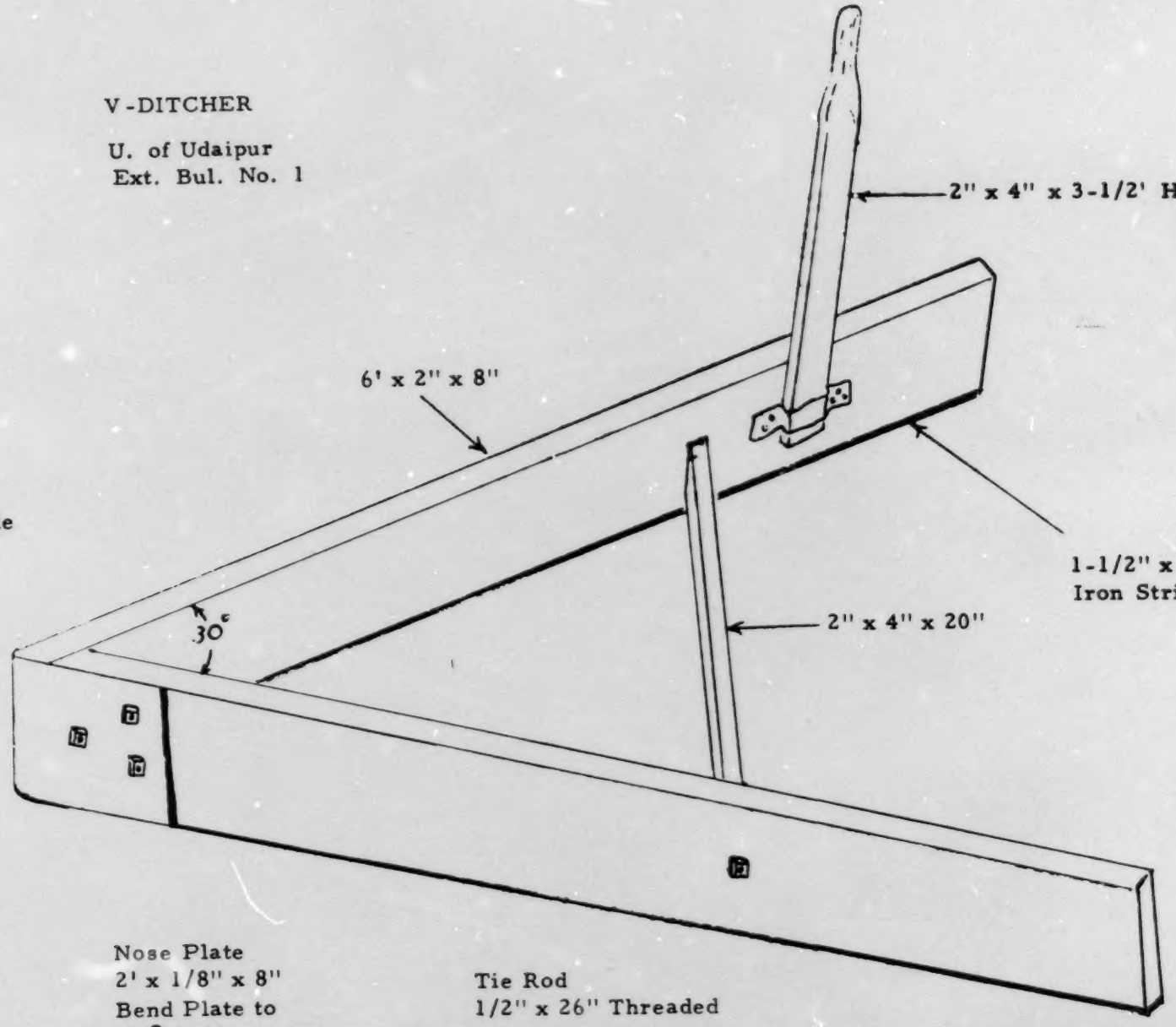
MATERIALS FOR A-FRAME RIDGER

NUMBER OF PIECES	DIMENSIONS	ITEM
2	2" x 8" x 6'	Runner
1	2" x 4" x 5'	Rear Brace
1	2" x 4" x 42"	Middle Brace
1	2" x 4" x 18"	Front Brace
1	2" x 4" x 5'	Center Brace
1	1" x 10'	Steel Chain
2	$\frac{1}{2}$" x 5"	Eye Bolt
15	3"	Nails
6	2" x 4" x 6"	Side Blocks
28	3" #12	Screws

V-DITCHER

U. of Udaipur
Ext. Bul. No. 1



MATERIALS FOR V-DITCHER

NUMBER OF PIECES	DIMENSIONS	ITEMS
2	2" x 10" x 6'	Wings
1	2" x 4" x 20"	Wing Brace
1	2" x 4" x 42"	Handle
1	$\frac{1}{2}$" x 28"	Steel Rod (threaded 2" on both ends)
2	$\frac{1}{2}$"	Nuts and Washers
1	$\frac{1}{4}$" x $1\frac{1}{2}$" x 12"	Iron Handle Bracket
1	$\frac{1}{2}$" x $4\frac{1}{2}$"	Carriage Bolt with Nut and Washer for handle
4	$\frac{1}{4}$" x 3"	Carriage Bolt with Nut and Washer - handle brace
2	$1\frac{1}{2}$" x 2" x 6'	Angle Iron
1	$\frac{1}{4}$" x 10" x 24"	Steel sheet for nose
2	$\frac{1}{2}$" x 7"	Carriage Bolt with Nut and Washer (nose)
20	$1\frac{1}{2}$" #12	Screws for fixing Angle Iron

TABLE I - List of Equivalents for Volume from Flow Units

One Acre Inch	=	3,630 cubic feet
	=	27,154 gallons
	=	1/12 acre foot
One Acre Foot	=	43,560 cubic feet
	=	325,851 gallons
One Acre Foot of Water	=	Approx. 2,722,500 pounds
One Acre Foot of Soil	=	Approx. 4,000,000 pounds
One Cubic Foot	=	1,728 cubic inches
	=	7.481 (approx. 7.5) gallons
	=	Weight (approx.) 62.4 pounds (62.39 at 55° F, 62.30 at 70° F, 62.00 at 100° F)
One Gallon	=	231 cubic inches
	=	0.13368 cubic feet, weighs approx. 8.33 pounds

Rate of Flow Units

One Cubic Foot Per Second	=	448.83 (approx. 450) gallons per minute
	=	1 acre inch 1 hour and 30 seconds (approx. 1 hour), or 0.992 (approx. 1) acre inch per hour.
	=	1 acre foot in 12 hours and 6 minutes (approx. 12 hours), or 1.984 (approx. 2 acre feet per day 24 hours)
One Gallon Per Minute	=	0.00223 (approx. 1/450 cubic foot per second)
	=	1 acre inch in 452.6 (approx. 450) hours or 0.00221 acre inch per hour
	=	1 acre feet in 226.3 days or 0.00442 acre foot per day
	=	1 inch depth of over 96.3 square feet in 1 hour
One Million Gallons Per Day	=	1.547 cubic feet per second
	=	694.4 gallons per minute

TABLE II - Flow Over Rectangular Contracted Weirs in Cubic Feet per Second*

Head in ft. "H"	Head in inches approx.	Crest length (L)					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.10	1 3/16	0.105	0.158	0.212	0.319	0.427	0.108
0.11	1 5/16	0.121	0.182	0.244	0.367	0.491	0.124
0.12	1 7/16	0.137	0.207	0.277	0.418	0.559	0.141
0.13	1 9/16	0.155	0.233	0.312	0.470	0.629	0.159
0.14	1 11/16	0.172	0.260	0.348	0.524	0.701	0.177
0.15	1 13/16	0.191	0.288	0.385	0.581	0.776	0.196
0.16	1 15/16	0.210	0.316	0.423	0.638	0.854	0.216
0.17	2 1/16	0.229	0.346	0.463	0.698	0.934	0.236
0.18	2 3/16	0.249	0.376	0.504	0.760	1.02	0.257
0.19	2 1/4	0.270	0.407	0.546	0.823	1.10	0.278
0.20	2 3/8	0.291	0.439	0.588	0.887	1.19	0.303
0.21	2 1/2	0.312	0.472	0.632	0.954	1.28	0.326
0.22	2 5/8	0.335	0.505	0.677	1.02	1.37	0.35
0.23	2 3/4	0.358	0.539	0.723	1.09	1.46	0.37
0.24	2 7/8	0.380	0.574	0.769	1.16	1.55	0.39
0.25	3	0.404	0.609	0.817	1.23	1.65	0.42
0.26	3 1/8	0.428	0.646	0.865	1.31	1.75	0.44
0.27	3 1/4	0.452	0.682	0.914	1.38	1.85	0.47
0.28	3 3/8	0.477	0.720	0.965	1.46	1.95	0.49
0.29	3 1/2	0.502	0.758	1.02	1.53	2.05	0.52

*(U. of Calif. Ext. Cir. 473)

TABLE II (Continued) Flow over Rectangular Contracted Weirs in Cubic Feet per Second

Head in ft. "H"	Head in inches approx.	Crest Length (L)					For each additional foot of crest in excess of 4 feet. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.30	3 5/8	0.527	0.796	1.07	1.61	2.16	0.55
0.31	3 3/4	0.553	0.836	1.12	1.69	2.26	0.57
0.32	3 13/16	0.580	0.876	1.18	1.77	2.37	0.60
0.33	3 15/16	0.606	0.916	1.23	1.86	2.48	0.62
0.34	4 1/16	0.634	0.957	1.28	1.94	2.60	0.66
0.35	4 3/16	0.661	0.999	1.34	2.02	2.71	0.69
0.36	4 5/16	0.688	1.04	1.40	2.11	2.82	0.71
0.37	4 7/16	0.717	1.08	1.45	2.20	2.94	0.74
0.38	4 9/16	0.745	1.13	1.51	2.28	3.06	0.78
0.39	4 11/16	0.774	1.17	1.57	2.37	3.18	0.81
0.40	4 13/16	0.804	1.21	1.63	2.46	3.30	0.84
0.41	4 15/16	0.833	1.26	1.69	2.55	3.42	0.87
0.42	5 1/16	0.863	1.30	1.75	2.65	3.54	0.89
0.43	5 3/16	0.893	1.35	1.81	2.74	3.67	0.93
0.44	5 1/4	0.924	1.40	1.88	2.83	3.80	0.97
0.45	5 3/8	0.955	1.44	1.94	2.93	3.93	1.00
0.46	5 1/2	0.986	1.49	2.00	3.03	4.05	1.02
0.47	5 5/8	1.02	1.54	2.07	3.12	4.18	1.06
0.48	5 3/4	1.05	1.59	2.13	3.22	4.32	1.10
0.49	5 7/8	1.08	1.64	2.20	3.32	4.45	1.13

TABLE II (Continued) Flow over Rectangular Contracted Weirs in Cubic Feet per Second

Head in feet "H"	Head in inches approx.	Crest Length(L)					For each additional foot of crest in excess of 4 feet. (approx).
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.50	6	1.11	1.68	2.26	3.42	4.58	1.16
0.51	6 1/8	1.15	1.73	2.33	3.52	4.72	1.20
0.52	6 1/4	1.18	1.78	2.40	3.62	4.86	1.24
0.53	6 3/8	1.21	1.84	2.46	3.73	4.99	1.26
0.54	6 1/2	1.25	1.89	2.53	3.83	5.13	1.30
0.55	6 5/8	1.28	1.94	2.60	3.94	5.27	1.33
0.56	6 3/4	1.31	1.99	2.67	4.04	5.42	1.38
0.57	6 13/16	1.35	2.04	2.74	4.15	5.56	1.41
0.58	6 15/16	1.38	2.09	2.81	4.26	5.70	1.44
0.59	7 1/16	1.42	2.15	2.88	4.36	5.85	1.49
0.60	7 3/16	1.45	2.20	2.96	4.47	6.00	1.53
0.61	7 5/16	1.49	2.25	3.03	4.59	6.14	1.55
0.62	7 7/16	1.52	2.31	3.10	4.69	6.29	1.60
0.63	7 9/16	1.56	2.36	3.17	4.81	6.44	1.63
0.64	7 11/16	1.60	2.42	3.25	4.92	6.59	1.67
0.65	7 13/16	1.63	2.47	3.32	5.03	6.75	1.72
0.66	7 15/16	1.67	2.53	3.40	5.15	6.90	1.75
0.67	8 1/16	1.71	2.59	3.47	5.26	7.07	1.79
0.68	8 3/16	1.74	2.64	3.56	5.38	7.23	1.83
0.69	8 1/4	1.78	2.70	3.63	5.49	7.36	1.87

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TABLE II (Continued) Flow over Rectangular Contracted Weirs in Cubic Feet per Second

Head in feet "H"	Head in inches approx	Crest Length (L)					For each additional foot of crest in excess of 4 feet. (approx).
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.70	8 3/8	1.82	2.76	3.71	5.61	7.52	1.91
0.71	8 1/2	1.86	2.81	3.78	5.73	7.68	1.95
0.72	8 5/8	1.90	2.87	3.86	5.85	7.84	1.99
0.73	8 3/4	1.93	2.93	3.94	5.97	8.00	2.03
0.74	8 7/8	1.97	2.99	4.02	6.09	8.17	2.08
0.75	9	2.01	3.05	4.10	6.21	8.33	2.12
0.76	9 1/8	2.05	3.11	4.18	6.33	8.49	2.16
0.77	9 1/4	2.09	3.17	4.26	6.45	8.66	2.21
0.78	9 3/8	2.13	3.23	4.34	6.58	8.82	2.24
0.79	9 1/2	2.17	3.29	4.42	6.70	8.99	2.29
0.80	9 5/8	2.21	3.35	4.51	6.83	9.16	2.33
0.81	9 3/4	2.25	3.41	4.59	6.95	9.33	2.38
0.82	9 13/16	2.29	3.47	4.67	7.08	9.50	2.42
0.83	9 15/16	2.33	3.54	4.75	7.21	9.67	2.46
0.84	10 1/16	2.37	3.60	4.84	7.33	9.84	2.51
0.85	10 3/16	2.41	3.66	4.92	7.46	10.01	2.55
0.86	10 5/16	2.46	3.72	5.01	7.59	10.19	2.60
0.87	10 7/16	2.50	3.79	5.10	7.72	10.36	2.64
0.88	10 9/16	2.54	3.85	5.18	7.85	10.54	2.69
0.89	10 11/16	2.58	3.92	5.27	7.99	10.71	2.72

TABLE II (Continued) Flow over Rectangular Contracted Weirs in Cubic Feet per Second

Head in feet "H"	Head in inches approx.	Crest Length(L)					For each additional foot of crest in excess of 4 feet. (approx).
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.90	10 13/16	2.62	3.98	5.35	8.12	10.89	2.77
0.91	10 15/16	2.67	4.05	5.44	8.25	11.07	2.82
0.92	11 1/16	2.71	4.11	5.53	8.38	11.25	2.87
0.93	11 3/16	2.75	4.18	5.62	8.52	11.43	2.91
0.94	11 1/4	2.79	4.24	5.71	8.65	11.61	2.96
0.95	11 3/8	2.84	4.31	5.80	8.79	11.79	3.00
0.96	11 1/2	2.88	4.37	5.89	8.93	11.98	3.05
0.97	11 5/8	2.93	4.44	5.98	9.06	12.16	3.10
0.98	11 3/4	2.97	4.51	6.07	9.20	12.34	3.14
0.99	11 7/8	3.01	4.57	6.15	9.34	12.53	3.19
1.00	12	3.06	4.64	6.25	9.48	12.72	3.24
1.01	12 1/8	----	4.71	6.34	9.62	12.91	3.29
1.02	12 1/4	----	4.78	6.43	9.76	13.10	3.34
1.03	12 3/8	----	4.85	6.52	9.90	13.28	3.38
1.04	12 1/2	----	4.92	6.62	10.04	13.47	3.43
1.05	12 5/8	----	4.98	6.71	10.18	13.66	3.48
1.06	12 3/4	----	5.05	6.80	10.32	13.85	3.53
1.07	12 13/16	----	5.12	6.90	10.46	14.04	3.58
1.08	12 15/16	----	5.20	6.99	10.61	14.24	3.63
1.09	13 1/16	----	5.26	7.09	10.75	14.43	3.68

TABLE II (Continued) Flow over Rectangular Contracted Weirs in Cubic Feet per Second

Head in feet "H"	Head in inches approx.	Crest Length (L)					For each additional foot of crest in excess of 4 feet. (approx).
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
1.10	13 3/16	----	5.34	7.19	10.90	14.64	3.74
1.11	13 5/16	----	5.41	7.28	11.04	14.83	3.79
1.12	13 7/16	----	5.48	7.38	11.19	15.03	3.84
1.13	13 9/16	----	5.55	7.47	11.34	15.22	3.88
1.14	13 11/16	----	5.62	7.57	11.48	15.42	3.94
1.15	13 13/16	----	5.69	7.66	11.64	15.62	3.98
1.16	13 15/16	----	5.77	7.76	11.79	15.82	4.03
1.17	14 1/16	----	5.84	7.86	11.94	16.02	4.08
1.18	14 3/16	----	5.91	7.96	12.09	16.23	4.14
1.19	14 1/4	----	5.98	8.06	12.24	16.43	4.19
1.20	14 3/8	----	6.06	8.16	12.39	16.63	4.24
1.21	14 1/2	----	6.13	8.26	12.54	16.83	4.29
1.22	14 5/8	----	6.20	8.35	12.69	17.03	4.34
1.23	14 3/4	----	6.28	8.46	12.58	17.25	4.40
1.24	14 7/8	----	6.35	8.56	12.99	17.45	4.46
1.25	15	----	6.43	8.66	13.14	17.65	4.51
1.26	15 1/8	----	----	----	13.30	17.87	4.57
1.27	15 1/4	----	----	----	13.45	18.07	4.62
1.28	15 5/8	----	----	----	13.61	18.28	4.67
1.29	15 1/2	----	----	----	13.77	18.50	4.73

TABLE II (Continued) Flow over Rectangular Contracted Weirs in Cubic Feet per Second

Head in feet "H"	Head in inches approx.	Crest Length (L)					For each additional foot of crest in excess 0f 4 feet (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
1.30	15 5/8	----	----	----	13.93	18.71	4.78
1.31	15 3/4	----	----	----	14.09	18.92	4.82
1.32	15 13/16	----	----	----	14.24	19.12	4.88
1.33	15 15/16	----	----	----	14.40	19.34	4.94
1.34	16 1/16	----	----	----	14.56	19.55	4.99
1.35	16 3/16	----	----	----	14.72	19.77	5.05
1.36	16 5/16	----	----	----	14.88	19.98	5.10
1.37	16 7/16	----	----	----	15.04	20.20	5.16
1.38	16 9/16	----	----	----	15.20	20.42	5.22
1.39	16 11/16	----	----	----	15.36	20.64	5.28
1.40	16 13/16	----	----	----	15.53	20.86	5.33
1.41	16 15/16	----	----	----	15.69	21.08	5.39
1.42	17 1/16	----	----	----	15.85	21.29	5.44
1.43	17 3/16	----	----	----	16.02	21.52	5.50
1.44	17 1/4	----	----	----	16.19	21.74	5.55
1.45	17 3/8	----	----	----	16.34	21.96	5.62
1.46	17 1/2	----	----	----	16.51	22.18	5.67
1.47	17 5/8	----	----	----	16.68	22.41	5.73
1.48	17 3/4	----	----	----	16.85	22.64	5.79
1.49	17 7/8	----	----	----	17.01	22.85	5.84
1.50	18	----	----	----	17.17	23.08	5.91

TABLE III - Flow over 90° V-Notch Weir in Cubic Feet per Second and Gallons per Minute

Head in feet "H"	Head in inches (approximate)	Flow in cubic feet per second	Flow in gallons per minute
0.10	1 3/16	0.008	3.6
0.11	1 5/16	0.010	4.5
0.12	1 7/16	0.012	5.4
0.13	1 9/16	0.016	7.2
0.14	1 11/16	0.019	8.5
0.15	1 13/16	0.022	9.9
0.16	1 15/16	0.026	11.7
0.17	2 1/16	0.031	13.9
0.18	2 3/16	0.035	15.7
0.19	2 1/4	0.040	18.0
0.20	2 3/8	0.046	20.6
0.21	2 1/2	0.052	23.3
0.22	2 5/8	0.058	26.0
0.23	2 3/4	0.065	29.2
0.24	2 7/8	0.072	32.3
0.25	3	0.080	35.9
0.26	3 1/8	0.088	39.5
0.27	3 1/4	0.096	43.1
0.28	3 3/8	0.106	47.6
0.29	3 1/2	0.115	51.6
0.30	3 5/8	0.125	56.1
0.31	3 3/4	0.136	61.0
0.32	3 13/16	0.147	66.0
0.33	3 15/16	0.159	71.4
0.34	4 1/16	0.171	76.7
0.35	4 3/16	0.184	82.6
0.36	4 5/16	0.197	88.4
0.37	4 7/16	0.211	94.7
0.38	4 9/16	0.226	101.0
0.39	4 11/16	0.240	108.0

TABLE III - (Continued) - Flow over 90° V-Notch Weir in Cubic Feet per Second and Gallons per Minute

Head in feet "H"	Head in inches approximate	Flow in cubic feet per second	Flow in gallons per minute
0.40	4 13/16	0.256	115
0.41	4 15/16	0.272	122
0.42	5 1/16	0.289	130
0.43	5 3/16	0.306	137
0.44	5 1/4	0.324	145
0.45	5 3/8	0.343	154
0.46	5 1/2	0.362	162
0.47	5 5/8	0.382	171
0.48	5 3/4	0.403	181
0.49	5 7/8	0.424	190
0.50	6	0.445	200
0.51	6 1/8	0.468	210
0.52	6 1/4	0.491	220
0.53	6 3/8	0.515	231
0.54	6 1/2	0.539	242
0.55	6 5/8	0.564	253
0.56	6 3/4	0.590	265
0.57	6 13/16	0.617	277
0.58	6 15/16	0.644	289
0.59	7 1/16	0.672	302
0.60	7 3/16	0.700	314
0.61	7 5/16	0.730	328
0.62	7 7/16	0.760	341
0.63	7 9/16	0.790	355
0.64	7 11/16	0.822	369
0.65	7 13/16	0.854	383
0.66	7 15/16	0.887	398
0.67	8 1/16	0.921	413
0.68	8 3/16	0.955	429
0.69	8 1/4	0.991	445

TABLE III - (Continued) - Flow over 90° V-Notch Weir in Cubic Feet per Second and Gallons per Minute

Head in feet "H"	Head in inches (approximate)	Flow in Cubic feet per second	Flow in gallons per minute
0.70	8 3/8	1.03	462
0.71	8 1/2	1.06	476
0.72	8 5/8	1.10	494
0.73	8 3/4	1.14	512
0.74	8 7/8	1.18	530
0.75	9	1.22	548
0.76	9 1/8	1.26	566
0.77	9 1/4	1.30	583
0.78	9 3/8	1.34	601
0.79	9 1/2	1.39	624
0.80	9 5/8	1.43	642
0.81	9 3/4	1.48	664
0.82	9 13/16	1.52	682
0.83	9 15/16	1.57	705
0.84	10 1/16	1.61	723
0.85	10 3/16	1.66	745
0.86	10 5/16	1.71	767
0.87	10 7/16	1.76	790
0.88	10 9/16	1.81	812
0.89	10 11/16	1.86	835
0.90	10 13/16	1.92	862
0.91	10 15/16	1.97	884
0.92	11 1/16	2.02	907
0.93	11 3/16	2.08	934
0.94	11 1/4	2.13	956
0.95	11 3/8	2.19	983
0.96	11 1/2	2.25	1,010
0.97	11 5/8	2.31	1,037
0.98	11 3/4	2.37	1,064
0.99	11 7/8	2.43	1,091

TABLE III - (Continued) - Flow over 90° V-Notch Weir in Cubic Feet per Second and Gallons per Minute

Head in feet "H"	Head in inches (approximate)	Flow in Cubic feet per second	Flow in gallons per minute
1.00	12	2.49	1,118
1.01	12 1/8	2.55	1,145
1.02	12 1/4	2.61	1,171
1.03	12 3/8	2.68	1,203
1.04	12 1/2	2.74	1,230
1.05	12 5/8	2.81	1,261
1.06	12 3/4	2.87	1,288
1.07	12 13/16	2.94	1,320
1.08	12 15/16	3.01	1,351
1.09	13 1/16	3.08	1,382
1.10	13 3/16	3.15	1,414
1.11	13 5/16	3.22	1,445
1.12	13 7/16	3.30	1,481
1.13	13 9/16	3.37	1,513
1.14	13 11/16	3.44	1,544
1.15	13 13/16	3.52	1,580
1.16	13 15/16	3.59	1,611
1.17	14 1/16	3.67	1,647
1.18	14 3/16	3.75	1,683
1.19	14 1/4	3.83	1,719
1.20	14 3/8	3.91	1,755
1.21	14 1/2	3.99	1,791
1.22	14 5/8	4.07	1,827
1.23	14 3/4	4.16	1,867
1.24	14 7/8	4.24	1,903
1.25	15	4.33	1,943

TABLE IV - Flow Over Cipolletti Weirs in Cubic Feet per Second*

Head in ft. "H"	Head in inches approx.	Crest length (L)					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.10	1 3/16	0.107	0.160	0.214	0.321	0.429	0.108
0.11	1 5/16	0.123	0.185	0.246	0.370	0.494	0.124
0.12	1 7/16	0.140	0.210	0.280	0.421	0.562	0.141
0.13	1 9/16	0.158	0.237	0.316	0.474	0.632	0.159
0.14	1 11/16	0.177	0.264	0.352	0.528	0.706	0.177
0.15	1 13/16	0.195	0.293	0.390	0.586	0.782	0.196
0.16	1 15/16	0.216	0.322	0.430	0.644	0.860	0.216
0.17	2 1/16	0.237	0.353	0.470	0.705	0.941	0.236
0.18	2 3/16	0.258	0.384	0.512	0.768	1.024	0.257
0.19	2 1/4	0.280	0.417	0.555	0.832	1.110	0.278
0.20	2 3/8	0.302	0.450	0.599	0.898	1.20	0.302
0.21	2 1/2	0.324	0.484	0.644	0.966	1.29	0.324
0.22	2 5/8	0.349	0.519	0.691	1.04	1.38	0.35
0.23	2 3/4	0.374	0.555	0.739	1.11	1.47	0.37
0.24	2 7/8	0.397	0.591	0.786	1.18	1.57	0.39
0.25	3	0.423	0.628	0.836	1.25	1.67	0.42
0.26	3 1/8	0.449	0.667	0.886	1.33	1.77	0.44
0.27	3 1/4	0.475	0.705	0.937	1.40	1.87	0.47
0.28	3 3/8	0.502	0.745	0.990	1.48	1.97	0.49
0.29	3 1/2	0.529	0.785	1.04	1.56	2.08	0.52

*Computed from Cone's formula:

$$Q = 3.247\, LH^{1.48} - \frac{0.566\, L^{1.8}}{1 + 2\, L^{1.8}}\, H^{1.9} + 0.609\, H^{2.5}.$$

TABLE IV (Continued) - Flow Over Cipolletti Weirs in Cubic Feet per Second

Head in ft. "H"	Head in inches approx.	Crest length (L)					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.30	3 5/8	0.557	0.827	1.10	1.64	2.19	0.55
0.31	3 3/4	0.586	0.869	1.15	1.73	2.30	0.57
0.32	3 13/16	0.615	0.911	1.21	1.81	2.41	0.60
0.33	3 15/16	0.644	0.954	1.27	1.89	2.52	0.62
0.34	4 1/16	0.675	1.00	1.32	1.98	2.64	0.66
0.35	4 3/16	0.705	1.04	1.38	2.07	2.75	0.69
0.36	4 5/16	0.735	1.09	1.44	2.16	2.87	0.71
0.37	4 7/16	0.767	1.13	1.50	2.25	2.99	0.74
0.38	4 9/16	0.799	1.18	1.57	2.34	3.11	0.78
0.39	4 11/16	0.832	1.23	1.63	2.43	3.24	0.81
0.40	4 13/16	0.866	1.28	1.69	2.53	3.36	0.84
0.41	4 15/16	0.899	1.32	1.76	2.62	3.49	0.87
0.42	5 1/16	0.932	1.37	1.82	2.72	3.61	0.89
0.43	5 3/16	0.967	1.42	1.89	2.81	3.74	0.93
0.44	5 1/4	1.00	1.47	1.95	2.91	3.87	0.97
0.45	5 3/8	1.04	1.53	2.02	3.01	4.01	1.00
0.46	5 1/2	1.07	1.58	2.09	3.11	4.14	1.02
0.47	5 5/8	1.11	1.63	2.16	3.21	4.28	1.06
0.48	5 3/4	1.15	1.68	2.23	3.32	4.41	1.10
0.49	- 5 7/8	1.18	1.74	2.30	3.42	4.55	1.13

TABLE IV (Continued) - Flow Over Cipolletti Weirs in Cubic Feet per Second

Head in ft. "H"	Head in inches approx.	Crest length (L)					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.50	6	1.22	1.79	2.37	3.53	4.69	1.16
0.51	6 1/8	1.26	1.85	2.44	3.64	4.83	1.20
0.52	6 1/4	1.30	1.90	2.51	3.74	4.97	1.24
0.53	6 3/8	1.34	1.96	2.59	3.85	5.12	1.26
0.54	6 1/2	1.38	2.02	2.66	3.96	5.26	1.30
0.55	6 5/8	1.42	2.07	2.74	4.07	5.41	1.33
0.56	6 3/4	1.46	2.13	2.81	4.18	5.56	1.38
0.57	6 13/16	1.50	2.19	2.89	4.30	5.71	1.41
0.58	6 15/16	1.54	2.25	2.97	4.41	5.86	1.44
0.59	7 1/16	1.58	2.31	3.05	4.53	6.01	1.49
0.60	7 3/16	1.62	2.37	3.13	4.64	6.17	1.53
0.61	7 5/16	1.67	2.43	3.20	4.76	6.32	1.55
0.62	7 7/16	1.71	2.49	3.28	4.88	6.47	1.60
0.63	7 9/16	1.75	2.55	3.37	5.00	6.63	1.63
0.64	7 11/16	1.80	2.62	3.45	5.12	6.79	1.67
0.65	7 13/16	1.84	2.68	3.53	5.24	6.95	1.72
0.66	7 15/16	1.89	2.75	3.61	5.36	7.11	1.75
0.67	8 1/16	1.93	2.81	3.70	5.48	7.28	1.79
0.68	8 3/16	1.98	2.87	3.79	5.61	7.44	1.83
0.69	8 1/4	2.02	2.94	3.87	5.73	7.61	1.87

TABLE IV (Continued) - Flow Over Cipolletti Weirs in Cubic Feet per Second

Head in ft. "H"	Head in inches approx.	Crest length (L)					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.70	8 3/8	2.07	3.01	3.95	5.86	7.77	1.91
0.71	8 1/2	2.12	3.07	4.04	5.99	7.94	1.95
0.72	8 5/8	2.16	3.14	4.13	6.12	8.11	1.99
0.73	8 3/4	2.21	3.21	4.22	6.24	8.28	2.03
0.74	8 7/8	2.26	3.28	4.31	6.38	8.45	2.08
0.75	9	2.31	3.35	4.40	6.51	8.62	2.12
0.76	9 1/8	2.36	3.42	4.49	6.64	8.80	2.16
0.77	9 1/4	2.41	3.49	4.58	6.77	8.97	2.21
0.78	9 3/8	2.46	3.56	4.67	6.90	9.15	2.24
0.79	9 1/2	2.51	3.63	4.76	7.04	9.33	2.29
0.80	9 5/8	2.56	3.70	4.85	7.18	9.51	2.33
0.81	9 3/4	2.61	3.77	4.95	7.31	9.69	2.38
0.82	9 13/16	2.66	3.84	5.04	7.45	9.87	2.42
0.83	9 15/16	2.71	3.92	5.14	7.59	10.05	2.46
0.84	10 1/16	2.77	3.99	5.23	7.73	10.23	2.51
0.85	10 3/16	2.82	4.07	5.33	7.87	10.42	2.55
0.86	10 5/16	2.87	4.14	5.43	8.01	10.60	2.60
0.87	10 7/16	2.93	4.22	5.52	8.15	10.79	2.64
0.88	10 9/16	2.98	4.29	5.62	8.30	10.98	2.69
0.89	10 11/16	3.04	4.37	5.72	8.44	11.17	2.72

TABLE IV (Continued) - Flow Over Cipolletti Weirs in Cubic Feet per Second

Head in ft. "H"	Head in inches approx.	Crest length (L)					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
0.90	10 13/16	3.09	4.45	5.82	8.59	11.36	2.77
0.91	10 15/16	3.15	4.53	5.92	8.73	11.55	2.82
0.92	11 1/16	3.20	4.60	6.02	8.88	11.74	2.87
0.93	11 3/16	3.26	4.68	6.13	9.03	11.94	2.91
0.94	11 1/4	3.32	4.76	6.23	9.17	12.13	2.96
0.95	11 3/8	3.37	4.84	6.33	9.32	12.33	3.00
0.96	11 1/2	3.43	4.92	6.44	9.48	12.53	3.05
0.97	11 5/8	3.49	5.00	6.55	9.62	12.72	3.10
0.98	11 3/4	3.55	5.09	6.64	9.78	12.92	3.14
0.99	11 7/8	3.61	5.17	6.75	9.93	13.12	3.19
1.00	12	3.67	5.25	6.86	10.08	13.32	3.24
1.01	12 1/8	----	5.33	6.96	10.24	13.53	3.29
1.02	12 1/4	----	5.42	7.07	10.40	13.73	3.34
1.03	12 3/8	----	5.50	7.18	10.55	13.94	3.38
1.04	12 1/2	----	5.59	7.29	10.71	14.15	3.43
1.05	12 5/8	----	5.67	7.40	10.87	14.35	3.48
1.06	12 3/4	----	5.76	7.51	11.03	14.56	3.53
1.07	12 13/16	----	5.84	7.62	11.18	14.76	3.58
1.08	12 15/16	----	5.93	7.73	11.35	14.98	3.63
1.09	13 1/16	----	6.02	7.84	11.51	15.19	3.68

TABLE IV (Continued) - Flow Over Cipolletti Weirs in Cubic Feet per Second

Head in ft. "H"	Head in inches approx.	Crest length (L)					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
1.10	13 3/16	----	6.11	7.96	11.68	15.41	3.74
1.11	13 5/16	----	6.20	8.07	11.84	15.62	3.79
1.12	13 7/16	----	6.29	8.18	12.00	15.84	3.84
1.13	13 9/16	----	6.37	8.29	12.16	16.04	3.88
1.14	13 11/16	----	6.46	8.41	12.33	16.26	3.94
1.15	13 13/16	----	6.56	8.53	12.50	16.48	3.98
1.16	13 15/16	----	6.65	8.65	12.67	16.70	4.03
1.17	14 1/16	----	6.74	8.76	12.84	16.93	4.08
1.18	14 3/16	----	6.83	8.88	13.01	17.15	4.14
1.19	14 1/4	----	6.93	9.00	13.18	17.37	4.19
1.20	14 3/8	----	7.02	9.12	13.35	17.59	4.24
1.21	14 1/2	----	7.11	9.24	13.52	17.81	4.29
1.22	14 5/8	----	7.20	9.36	13.69	18.03	4.34
1.23	14 3/4	----	7.30	9.48	13.87	18.27	4.40
1.24	14 7/8	----	7.40	9.60	14.04	18.49	4.46
1.25	15	----	7.49	9.72	14.21	18.71	4.51
1.26	15 1/8	----	----	----	14.39	18.95	4.57
1.27	15 1/4	----	----	----	14.56	19.17	4.62
1.28	15 3/8	----	----	----	14.74	19.41	4.67
1.29	15 1/2	----	----	----	14.92	19.65	4.73

TABLE IV (Continued) - Flow Over Cipolletti Weirs in Cubic Feet per Second

Head in ft. "H"	Head in inches approx.	Crest length (L)					For each additional foot of crest in excess of 4 ft. (approx.)
		1.0 foot	1.5 feet	2.0 feet	3.0 feet	4.0 feet	
		Flow in cubic feet per second					
1.30	15 5/8	----	----	----	15.11	19.88	4.78
1.31	15 3/4	----	----	----	15.29	20.12	4.82
1.32	15 13/16	----	----	----	15.46	20.34	4.88
1.33	15 15/16	----	----	----	15.64	20.58	4.94
1.34	16 1/16	----	----	----	15.82	20.82	4.99
1.35	16 3/16	----	----	----	16.01	21.06	5.05
1.36	16 5/16	----	----	----	16.19	21.29	5.10
1.37	16 7/16	----	----	----	16.37	21.53	5.16
1.38	16 9/16	----	----	----	16.57	21.78	5.22
1.39	16 11/16	----	----	----	16.75	22.02	5.28
1.40	16 13/16	----	----	----	16.94	22.27	5.33
1.41	16 15/16	----	----	----	17.13	22.51	5.39
1.42	17 1/16	----	----	----	17.31	22.75	5.44
1.43	17 3/16	----	----	----	17.51	23.01	5.50
1.44	17 1/4	----	----	----	17.70	23.26	5.55
1.45	17 3/8	----	----	----	17.89	23.50	5.62
1.46	17 1/2	----	----	----	18.08	23.75	5.67
1.47	17 5/8	----	----	----	18.28	24.01	5.73
1.48	17 3/4	----	----	----	18.47	24.26	5.79
1.49	17 7/8	----	----	----	18.66	24.50	5.84
1.50	18	----	----	----	18.85	24.75	5.91

SELECT READING LIST

Adams, F., Community Organization for Irrigation in the U.S., F.A.O. Agr. Dev. Paper #19. 1953

Ayers, Q.C. and Scoates, D., Land Drainage and Reclamation. Second edition. McGraw-Hill Book Co., New York. 1939

Brown, Lloyd N., Planting and Irrigating on the Contour. Calif. Agr. Ext. Cir. 523. 1963

California Fertilizer Association, Western Fertilizer Handbook. 1965

DeVajda, A., Some Aspects of Surface Water Development in Arid Regions. F.A.O. Agr. Dev. Paper #21. 1952

Dusenberry, H.L. and Monson, O.W., Irrigation Structures and Equipment. Mont. State Ext. Bul. No. 180.

Etcheverry, B.A. and Harding, S.T., Irrigation Practices and Engineering. McGraw-Hill, New York.

Houston, Clyde E., Drainage of Irrigated Land. Calif. Agr. Ext. Cir. 504. 1967

Houston, Clyde E. and Schade, Richard O., Irrigation Return - Water Systems. Calif. Agr. Exp. Sta. Cir. 542. 1966

Israelson, O.W. and Hansen, V.E., Irrigation Principles and Practices. John Wiley and Sons, Inc. 1962

Jones, L.A., Farm Drainage. U.S.D.A. Farm Bul. No. 2046. 1952

Marr, J.C., Grading Land for Surface Irrigation. Calif. Agr. Ext. Cir. 438. 1957

Marr, J.C., The Border Method of Irrigation. Calif. Agr. Ext. Cir. 408. 1952

Marr, J.C., Furrow Irrigation. Calif. Agr. Ext. Man. 37. 1967

Michael, A.M., et. al., Simple Bullock Drawn Implements for Efficient Irrigation. Univ. of Udaipur, Jobner, India. Ext. Bul. No. 1. 1964

Michael, A.M., et. al., How to Improve Irrigation Farming in India. Univ. of Udaipur. 1965

Michael, A.M., et. al., Cultivation Practices in Irrigation Farming. Univ. of Udaipur. 1965

Minehart, D.J., A Guide to Application of Irrigation Water. Delhi: Cambridge Printing Works.

Molenaar, A., Irrigation by Sprinkling. F.A.O. Agr. Dev. Paper No. 65. 1960

Molenaar, A., Water Lifting Devices for Irrigation. F.A.O. Agr. Dev. Paper No. 60. 1956

McCulloch, A.W. and Criddle, W.D., Conservation Irrigation. U.S.D.A. Agr. Inf. Bul. No. 8. 1950

Powers, W.L. and King, A.S., Drainage Practices for Oregon. Ore. Agr. Exp. Sta. Bul. 492. 1950

Schwab, G.O., et. al., Elementary Soil and Water Engineering. John Wiley and Sons, Inc., New York. 1966

Scott, Verne H. and Houston, C.E., Measuring Irrigation Water. Calif. Agr. Ext. Cir. 473. 1959

Soil Conservation Service, Irrigation on Western Farms. U.S.D.A. Agr. Inf. Bul. No. 199. 1959

Soil Conservation Service, Planning Farm Irrigation Systems. Handbook, Chapter 3. 1967

Thorne, D.W. and Peterson, H.B., Irrigated Soils. Blakiston Co. Inc., New York. 1954

U.S.A.I.D., A Guide to Application of Irrigation Water.

U.S.A.I.D., Village Technology Handbook I and II.

U.S.D.A., Yearbook of Agriculture Water. 1955

Zimmerman, J., Irrigation. John Wiley and Sons, Inc., New York.

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